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Whose lands' slides? Social vulnerability to landslides in Rio de Janeiro and how the local plans affect it.

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Whose lands' slides? Social vulnerability to landslides in Rio de Janeiro and how the local plans affect it.

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Abstract

Whose lands' slides: Social vulnerability to landslides in Rio de Janeiro and how the local plans affect it.

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Rio de Janeiro has major historical, economic, and political importance in Brazil. The city also has a long history of disasters, particularly landslides, and although there have been mitigation efforts, they are still a common occurrence. Disaster as a research field is particularly comprehensive as it involves many fields, from engineering to social sciences, and while there is no consensus in some of the issues related to the field, social vulnerability and resilience are frequently discussed concepts. Social vulnerability focuses on the pre-existing social, political, economic, and physical aspects of a community, whereas resilience is largely understood as the ability to adapt to change, and "bounce back" after a stressful event. Additionally, it is known that local planning is essential for disaster mitigation.

This work discusses the vulnerabilization process of the city of Rio de Janeiro and aims to contribute to the process of resilience building in the city by mapping social vulnerability and analyzing the current local policies in their ability to decrease social vulnerability. Literature about resilience, vulnerability to disasters, planning for disasters, and historic questions about Brazil and Rio de Janeiro was reviewed. The references used varied from official material produced by national and international agencies, newspaper articles, and academic sources. The materials were written in Portuguese, English, or Spanish. To map social vulnerability, CDC's SVI was adapted for the Brazilian context to generate an index comparing Census Sectors within the city. Finally, local plans and policies were evaluated following the process described in the Plan Integration for Resilience Scorecard (Malecha et al, 2019), where planning districts and risk areas are overlayed to highlight incongruities.

Results suggest that historical patterns of segregation still define the city. Correlations were found between overall social vulnerability and risk. However, Sectors with high vulnerability are located throughout the city, not only in risk areas. The policy evaluation showed a lack of quality and alignment between plans. To build resilience and prepare for climate change the city should make efforts to account for social vulnerability and risk in its policies, as well as improve the quality of its plans to implement them effectively.

Contents

List of Figures ix

List of Maps xi

List of Tables xiii

Introduction 1

Chapter 1: Literature Review 6

General Concepts 6

Planning for disasters 10

Social Vulnerability to Disasters 17

Vulnerabilization process in the City of Rio de Janeiro 25

Chapter 2: Methods 34

Defining Indicators 35

Mapping vulnerability 42

Relating Risk and Vulnerability 43

Plan Evaluation 44

Chapter 3: Results and Analysis 52

Social Vulnerability and Risk in Rio 52

Plan Network Evaluation 78

Chapter 4: Recommendations 117

Chapter 5: Final Remarks 121

Appendix 125

References 149

Literature 149

Map Sources 163

List of Figures

Figure 1: Map showing comparative social vulnerability index in Brazil, based on SoVI (Hummell et al., 2016, p. 121) 19

Figure 2: Vulnerability map for DRIB by municipality (Almeida et al., 2020, p. 10). 21

Figure 3: Overall risk map for DRIB by municipality (Almeida et al., 2020, p. 11). 22

Figure 4: The progression of vulnerability for the PAR model (Wisner et al., 2012, p.23). 24

Figure 5: Natural disasters occurrences identified by Vigiadesastres in the City of Rio de Janeiro, the emergency management program from the Department of Public Health. (SMS, n.d.) (Legend translation: Enxurrada = torrent / Alagamentos = flood / Deslizamentos = landslides / Risco Geológico = geological risk / Alagamentos – Rio Águas = flooding registered by Rio Águas.) 26

Figure 6: SVI indicators (CDC, 2020, p.3) 38

Figure 7: Final indicators for SVI for Brazil 41

Figure 8: Satellite image of Água Santa neighborhood (Google, 2021)........................... 80

Figure 9: Satellite image of Alto da Boa Vista neighborhood (Google, 2021). 82

Figure 10: Satellite image of Barra de Guaratiba neighborhood (Google, 2021)............. 83

Figure 11: Satellite image of Camorim neighborhood (Google, 2021). 84

Figure 12: Satellite image of Cavalcanti neighborhood (Google, 2021). 85

Figure 13: Satellite image of Complexo do Alemão neighborhood (Google, 2021). 87

Figure 14: Satellite image of Engenheiro Leal neighborhood (Google, 2021)................. 88

Figure 15: Satellite image of Grajaú neighborhood (Google, 2021). 89

Figure 16: Satellite image of Itanhangá neighborhood... 90

Figure 17: Satellite image of Joá neighborhood (Google, 2021)...................................... 91

Figure 18: Satellite image of Leme neighborhood (Google, 2021)................................... 93

Figure 19: Satellite image of Lins de Vasconcelos neighborhood (Google, 2021)........... 94

Figure 20: Satellite image of Mangueira neighborhood (Google, 2021)........................... 95

Figure 21: Satellite image of Rio Comprido neighborhood (Google, 2021)..................... 96

Figure 22: Satellite image of Rocinha neighborhood (Google, 2021)............................... 98

Figure 23: Satellite image of Santa Teresa neighborhood (Google, 2021)........................ 99

Figure 24: Satellite image of São Conrado neighborhood (Google, 2021). 100

Figure 25: Satellite image of Senador Camará neighborhood (Google, 2021)............... 102

Figure 26: Satellite image of Urca neighborhood (Google, 2021). 103

Figure 27: Satellite image of Vidigal neighborhood (Google, 2021). 104

Figure 28: Graph showing policy scoring by neighborhood. 107

List of Maps

Map 1: Susceptibility to landslides in the city of Rio. 62

Map 2: Map of Overall SVI. 63

Map 3: Socioeconomic category of SVI. 64

Map 4: Household category of SVI. 65

Map 5: Race and Language category of SVI. 66

Map 6: Built Environment Category of SVI 67

Map 7: Comparison of location of favelas, areas with high susceptibility to landslides, and Overall SVI (AP1 and AP2). 68

Map 8: Comparison of location of favelas, areas with high susceptibility to landslides, and Overall SVI (AP3 and AP4). 69

Map 9: Comparison of location of favelas, areas with high susceptibility to landslides, and Overall SVI (AP5). 70

Map 10: Selected neighborhoods for evaluation of plan network. 79

Map 11: Selected Neighborhoods - AP1 and AP2 Landslide Risk. 125

Map 12: Selected Neighborhoods - AP1 and AP2 Overall SVI 126

Map 13: Selected Neighborhoods - AP1 and AP2 Socioeconomic SVI 127

Map 14: Selected Neighborhoods - AP1 and AP2 Household SVI 128

Map 15: Selected Neighborhoods - AP1 and AP2 Race and Language SVI 129

Map 16: Selected Neighborhoods - AP1 and AP2 Built Environment SVI 130

Map 17: Selected Neighborhoods - AP 3 Landslide Risk 131

Map 18: Selected Neighborhoods - AP3 Overall SVI 132

Map 19: Selected Neighborhoods - AP 3 Socioeconomic SVI 133

Map 20: Selected Neighborhoods - AP3 Household SVI.. 134

Map 21: Selected Neighborhoods - AP3 Race and Language Vulnerability.................. 135

Map 22: Selected Neighborhoods - AP3 Built Environment SVI 136

Map 23: Selected Neighborhoods - Central AP4 and AP5 Landslide Risk.................... 137

Map 24: Selected Neighborhoods - Central AP4 and AP5 Overall SVI 138

Map 25: Selected Neighborhoods - Central AP4 and AP5 Socioeconomic SVI............ 139

Map 26: Selected Neighborhoods - Central AP4 and AP5 Household SVI................... 140

Map 27: Selected Neighborhoods - Central AP4 and AP5 Race and Language SVI..... 141

Map 28: Selected Neighborhoods - Central AP4 and AP5 Built Environment SVI 142

Map 29: Selected Neighborhoods - AP5 Landslide Risk 143

Map 30: Selected Neighborhoods - AP5 Overall SVI... 144

Map 31: Selected Neighborhoods - AP5 Socioeconomic SVI 145

Map 32: Selected Neighborhoods - AP5 Household SVI.. 146

Map 33: Selected Neighborhoods - AP5 Race and Language SVI 147

Map 34: Selected Neighborhoods - AP5 Built Environment SVI................................. 148

List of Tables

Table 1: Comparison of Census Sectors by Overall SVI Classes by AP. 53

Table 2: Comparison of Census Sectors by Overall SVI Classes Citywide. 53

Table 3: Comparison of Sectors by Socioeconomic Vulnerability Classes by AP. 55

Table 4: Comparison of Sectors by Socioeconomic Vulnerability Classes Citywide. 55

Table 5:Comparison of Sectors by Household Vulnerability Classes by AP. 56

Table 6: Comparison of Sectors by Household Vulnerability Classes Citywide. 56

Table 7: Comparison of Sectors by Race & Language Vulnerability Classes by AP. 57

Table 8: Comparison of Sectors by Race and Language Vulnerability Classes Citywide. 58

Table 9: Comparison of Sectors by Built Environment Vulnerability Classes by AP. 59

Table 10: Comparison of Sectors by Built Environment Vulnerability Classes Citywide. 59

Table 11: Pearson's correlation results for comparison between Sectors in medium and/or high-risk zones and all indicators. 74

Table 12: Pearson's correlation results for comparison between Sectors in high-risk zones and all indicators. 76

Table 13: Scoring of mappable policies by neighborhood. 106

Introduction

Rio de Janeiro is the second-largest metropolitan area in Brazil and has great historic, economic, political, and cultural importance. Nevertheless, it also has a long history of landslides and floods, and every year during the summer months there are news reports about major disruptions, and sometimes fatalities, in the city caused by these events. Although local politicians will say they are working to mitigate these problems, there is no noticeable reduction in disasters in the city. The present research was motivated by the will to understand if, in fact, local government is working to mitigate disasters in the city. To begin this work it was important to understand basic concepts in the field, such as resilience and social vulnerability, their relationship with risk, and how planning can help mitigate disasters.

Resilience is a concept that gained ground in the last decades, especially when discussing issues related to climate change. When applied to urban environments, it is broadly defined as the ability to recover from a stressful event and adapt to change (Cutter et al, 2008; Beilin & Wilkinson, 2015). Resilience building in urban environments can be one strategy for mitigating climate change since it is an adaptative process that considers short-term impacts and long-term changes (Sellberg et al., 2015; Sharifi & Yamagata, 2014). There are possibly three dimensions of building resilience, mitigation, adaptation, and innovation (Renald et al., 2016), and especially when considering mitigation and adaptation, preparing for natural disasters is essential.

Resilience and disaster risk reduction (DRR) are interconnected concepts, where building resilience help prevents disasters, and planning for DRR helps build resilience (Kim, 2015; Sharifi & Yamagata, 2014; Renald et al., 2016; Oliver-Smith et al., 2017).

Disasters are generally described as disruptions in everyday life (UNDRR, n.d. a), and disaster risk is defined as the interaction of a hazard with conditions of vulnerability, coping capacities, and mitigation strategies (Wisner et al., 2012). This definition considers the social aspects of disasters and implies that disasters are not natural but human-made. Although environmental hazards are natural, human development patterns are what cause loss of life and property.

One important step to DRR and resilience is to plan for disasters. A good plan should have elements such as specific goals, fact base policies, timelines, and monitoring tools (Baer, 1997; Berke & Godschalk, 2009), and a good plan has been shown to improve DRR and lower vulnerability (Kim, 2015; Berke et al., 2015). Not only plans should be internally good, but there needs to be integration between the different plans affecting a community, this way, avoiding conflicting policies (Malecha et al., 2018). Brazil has a history of local plans not being implemented, and zoning policies being the main way of organizing the built environment (Villaça, 1999). At the beginning of the 2000s, the creation of the City Statute increased the relevance of local planning, since it requires municipalities to develop a Comprehensive Plan every ten years (Brasil, 2002). Nevertheless, there is still progress to be made, although most municipalities in the country have developed comprehensive plans since then, there is still a lack of elements of good quality plans, such as implementation tools and timelines (Santos Junior & Montadon, 2011). Additionally, it is important to consider that, in Brazil, informality is intrinsic to urban development, and many local governments chose to not reinforce local plans (Maricato, 2003).

Another important element of DRR is dealing with social vulnerability, which are the pre-existing social, political, economic, and physical aspects of a community that can increase the impact a natural hazard can cause (Cutter et al, 2008; UNDRR, n.d. b).

Because of its importance, there are many efforts to measure social vulnerability, such as developing indexes to make it applicable to policymakers and practitioners. Social vulnerability indexes are a quantitative analysis that combines different indicators for demographic, social, economic, and physical characteristics of a community, and compares different geographical locations, generating relative levels of vulnerability for each. Two different social vulnerability studies in Brazil have found that municipalities in the North and Northeast regions of the country have higher levels of vulnerability, as well as big urban centers such as Rio de Janeiro and Sao Paulo.

However, it is important to notice that social vulnerability indexes only account for social conditions at a certain point in time, and because social vulnerability is not an observable characteristic they all present a level of imprecision (Spielman et al., 2020). To better understand the causes of vulnerability it is important to consider historic patterns of development (Valencio & Valencio, 2017). The Pressure and Release (PAR) model was developed to understand the vulnerabilization process of a community, it considers root causes, dynamic pressures, and their interaction with unsafe conditions (Wisner et al., 2012). This model is used in this research to understand the city of Rio de Janeiro, Brasil.

Rio is regularly impacted by landslides and floods, and the historic development patterns have forced low-income and black populations to occupy undesirable areas, which are normally also the areas with environmental risk (Marchezini & Wisner, 2017). Factors that contribute to the vulnerabilization of the city are: institutional fragility, which affects the quality and availability of disaster data (Marchezini et al., 2017), and the Civil Defense operations (Soriano et al., 2017); patrimonialism, which enables corruption (Valencio & Valencio, 2017); and violence (Benmergui & Gonçalves, 2019;

Pinto, 2019). Another important aspect is the city's geology, which makes it highly susceptible to landslides (Ramos, 2017).

In the 21st century, Rio de Janeiro has been making efforts to build resilience, for example, by creating the Operation Center of Rio (COR), as well as the Alerta Rio system, however, loss of life and property because of landslides is still common (Correia et al., 2021). With this in mind, the current research began with two general questions. First, what are the most socially vulnerable areas of the city, and do they coincide with areas of high risk to landslides? Second, are the current local policies adequately addressing landslide risk and social vulnerability? Since there has not been an apparent reduction in landslide losses, an initial hypothesis is that vulnerability is not being considered and local policies are not considering risk. To answer these questions the research process was divided into two parts, first the mapping and analysis of social vulnerability in the city, second, the evaluation of land-use policies that may affect landslide risk and social vulnerability.

To map social vulnerability the Social Vulnerability Index (SVI), developed by the Centers for Disease Control and Prevention (CDC) (Flanagan et al., 2011) was adapted to the Brazilian context. The final index is divided into four categories, socioeconomic status, household composition and disability, race and language, and built environment. These categories aim to account for different factors that might indicate that a community will be disproportionally affected by disasters. To evaluate if local planning was increasing or decreasing vulnerability it was important to evaluate land-use policies. Malecha et al. (2019) have developed the Plan Integration for Resilience Scorecard, which can be used by policymakers and practitioners to evaluate local policies and identify incongruities. This scorecard was used in the present work to evaluate land-use policies in Rio de Janeiro, Brazil.

The mapping of SVI and risk showed race and income have a significant correlation to where people are located around the city. Although areas of high social vulnerability are distributed throughout the city, areas of high landslide risk have mostly high social vulnerability. Historic patterns of segregation are observed, such as the South Zone of the city showing the lowest levels of vulnerability. After analyzing social vulnerability, the plan evaluation indicated a general lack of quality in the local plans and policies. Land-use policies were shown to ignore landslide risk, and policies developed by different departments conflicting with each other, for example, allowing development in environmentally protected areas.

Chapter 1: Literature Review

General Concepts

Climate change is a topic that has permeated almost all fields of knowledge, and some consider it the greatest political challenge for the international community in the 21st century. It is simultaneously a local and global challenge, requiring multiple levels of cooperation to be addressed. It is an already occurring phenomenon, and cities are key elements in our efforts to adapt to and mitigate climate change effects (UNDRR, 2019). Cities concentrate population, cultural, and economic activities, and can be particularly damaged by climate change effects. Additionally, they cause significant environmental impact by their considerable pollution, energy consumption, and consumerism of non-renewable raw materials (Martins & Ferreira, 2011). It is estimated that around 80% of global greenhouse gas emissions are related to urban environments (Fry et al., 2018). This way, they also affect non-urban areas by demanding large production of food and natural resources (Martins & Ferreira, 2011). Taking that into consideration, focusing on urban environments when adapting to climate change has become an essential task.

The concept of resilience embraces many of the concerns related to climate change and environmental issues. It is a concept that researchers have no consensus about, and each subject will have a specific definition, however, when related to urban environments it can be broadly understood as the ability of communities to bounce back from a stressful event (Cutter et al., 2008) and to adapt to change (Beilin & Wilkinson, 2015). Still, more specific definitions may differ slightly, the Resilience Alliance (2010) explains the concept as a system's property that refers to the magnitude of disturbance a system can experience without being functionally and structurally modified. Other definitions will explain resilience thinking and resilience assessment as strategic ways to address situations where there is little human control and high levels of uncertainty (Sellberg et al., 2015). Finally, resilience building can be defined as an adaptative process, with a resilient community being able to withstand short-term impact, develop over time, and cope with long-term changes (Sellberg et al., 2015; Sharifi & Yamagata, 2014).

It differs from the concept of sustainable development by addressing the dynamics of complex systems, understanding that socio-ecological systems are interlinked while focusing not only on individual events but what causes them (Sellberg et al., 2015). However, as pointed out by Beilin & Wilkinson (2015), the concept of resilience has been frequently politically exploited. Instead of being used as a tool for socio-ecological progress, it is often used to maintain the status quo of elites, by focusing on engineered responses to threats and shocks that simply aim to return a community to a previous 'stable' state. This way, risk management has become an industry, concentrated on techno-scientific approaches to measure, predict, and control risk (Beilin & Wilkinson, 2015).

When assessing resilience, it is important to consider that interlinked socio-ecological systems are complex and adaptive, and they interact across space and time. This reinforces the idea that there is no stable state in a system and different scales of human existence affect each other (Resilience Alliance, 2010; Sellberg et al., 2015).

Furthermore, Renald et al. (2016) identify three dimensions of resilience, which are: mitigation, defined as the reduction of risk relative to capacity, adaptation, meaning self-adjustment to risk, and innovation, meaning the creation and implementation of new technologies. Considering these, a key component to building resilient cities is preparing for natural hazards and climate change.

Resilience and disaster risk reduction (DRR) are interconnected concepts, making them almost impossible to dissociate, especially because climate change is increasing the frequency and severity of natural hazards (UNDRR, 2019). Also, planning for DRR has been proven to help create resilient communities since it focuses on adaptation and mitigation strategies to prevent disasters (Kim, 2015; Sharifi & Yamagata, 2014; Renald et al., 2016; Oliver-Smith et al., 2017). The complexity of modern society, where infrastructure is sophisticated, populations are large and settlements are denser, makes us more vulnerable to disasters in general. Since systems are connected, failure in one component such as a communication tower can create cascading effects such as limiting the government's capacity to respond to an event, affecting large portions of the population. How and where we live determines how well we can deal with hazards. This way, efforts to mitigate the impacts of environmental hazards consequently create resilient settlements. Conversely, higher levels of community resilience result in fewer losses from disasters (Kim, 2015; Gencer et al. 2018).

Disaster as a concept also has no exact definition, and how people choose to describe it changes the way they prepare for it. One understanding of disasters is that it is exclusively a physical phenomenon caused by environmental hazards, which normally translates to war-like responses that focus on fighting threats. When identifying disasters only as a natural event, the focus lies on technical solutions of engineering, such as slope contention works, measuring, and warning systems, which can create situations where efforts to mitigate disasters are outpaced by social processes that create them (Oliver-Smith et al., 2017). However, another explanation of disaster is that it is a disruption of the everyday life of a community (UNDRR, n.d. a). More specifically, disaster risk is the interaction of a hazard with conditions of vulnerability, coping capacities, and mitigation strategies[1] (Wisner et al., 2012). This definition understands that disasters are influenced by human activity, adding a social component to it, which renders responses that will focus on the causes of vulnerability (Siena, 2014; Marchezini et al., 2017). This way, to appraise the risk faced by a certain group it is necessary to evaluate: their exposure to an event, their susceptibility to loss and damage, their level of personal or social protection, and their capacity of coping with the event. (Marchezini, et al. 2017). Although most academic discussions have embraced the second definition, many governments still work with the first (Siena, 2014). Looking at disasters from a social standpoint implies that to

[1] "*Disaster risk is a function of the magnitude, potential occurrence, frequency, speed of onset and spatial extent of a potentially harmful natural event or process (the 'hazard'). It is also a function of people's susceptibility to loss, injury* or *death. Also, some people are better placed to recover quickly from such losses than others. Taken together, susceptibility to harm and the process that creates and maintains that susceptibility to harm can be called 'vulnerability'. Vulnerability, in turn, may be counteracted either by individual and local capacity for protective action (C) or by protective actions carried out by larger entities such as government (M, which stands for mitigation and prevention). So, in fact, DR = H x V can be expanded and rewritten as the following mnemonic (Wisner et al. 2004):*

DR = H x [(V/C) - M],

where DR is disaster risk, V stands for vulnerability, C represents capacity for personal protection and M symbolises larger-scale risk mitigation by preventive action and social protection." (Wisner et al, 2012, p.24) deal with risks we need to go beyond only technical solutions of engineering work and weather monitoring.

Climate change is a global issue, and one way of dealing with it is to make our cities more resilient. Resilience is a concept that has been the focus of many researchers recently, and although there is no consensus about its definition, it normally refers to the ability of a community to successfully recover from a traumatic event and adapt to future stressors, and one important way to achieve resilience is to mitigate disasters. Disasters are the result of a natural hazard interacting with conditions of social and environmental vulnerability. This way, when building resilience, it is necessary to consider not only protection against natural hazards but also the social processes that make communities vulnerable. An initial step to improve resilience is planning for disasters, especially at the local level.

PLANNING FOR DISASTERS

An appropriate disaster contingency plan has been proven to increase disaster recovery and lower vulnerability. Many scholars have pointed out that quality plans should contain specific goals, which should be based on local conditions, policies based on fact-finding, community engagement, and practical policies (Baer, 1997; Berke et al., 2015). Some specific policies that strengthen disaster resilience include: policies of land use planning, focused on disaster mitigation and environmental preservation; designing local infrastructure and facilities with a focus on resilience; creating financial policies that limit development in risk areas; establishing actions that benefit and recover natural environments; and creating codes and regulations related to building and structural resilience (Kim, 2015; Berke et al., 2015).

Making a good plan is no easy task, even if an agency has good staff capacity. Berke & Godschalk (2009), did a meta-analysis of plan quality papers from 1995 to 2007, and identified ten characteristics of quality plans:

> *We identified seven internal characteristics, with characteristics 1 through 6 reflecting the sequence of tasks in making plan elements that comprise a comprehensive plan. The sequence starts with issue identification and visioning (1), followed by direction-setting elements that include goals (2), fact base for policy selection (3), and policies for guiding future settlement patterns (4). Characteristics 1 through 4 provide the foundation for plan implementation actions (5), and monitoring and evaluation (6) that tracks and assesses the effectiveness of the plan in resolving issues and achieving goals. Finally, internal consistency (7) addresses how well the first six plan elements are integrated. Three external characteristics include organization and presentation (8) to foster comprehension and understandability of the plan, interorganizational coordination (9) to facilitate coordination among other plans (e.g., transportation, open space, housing, hazard mitigation), and compliance to ensure consistency with federal and state mandates (10).* (Berke & Godschalk, 2009, P.230)

Additionally, another important element is community engagement, which is shown to improve plan quality and create more creative policy solutions (Whyte et al., 1989). Including local knowledge in decision-making can increase procedural democracy and distributive justice by including the voices of marginalized groups, and it can also increase the effectiveness of policies since local communities can help identify low-cost solutions that align with the local reality (Corburn, 2003). Current adaptation planning many times limits itself to just inform civil society, without an effort to promote cooperation in the planning process, however, lack of adequate participation limits resilience-building since vulnerable groups have specific needs, such as evacuation assistance or social security services (Shi et al., 2016).

To achieve and maintain resilience not only do individual plans need to be of good quality, but it is also important for plans and policies from different agencies to be coordinated. Any action that can have an impact on the built environment can impact resilience, even if they are not directly related to hazards (Malecha et al., 2018). Hazard mitigation is normally not included in other planning efforts, however, it should be integrated into any planning activity. Not only plans should focus on hazards, but research has shown that local plans that focus on reducing vulnerability can bring a positive impact in creating resilience. When plans are not integrated or consistent between each other there is a greater possibility of conflicts between each other, for example, land use plans designating protection areas but capital improvement plans locating new infrastructure in those same areas (Berke et al. 2015).

Malecha et al. (2019), realizing the importance of plan integration to reduce vulnerability and increase resilience have developed the Plan Integration for Resilience Scorecard. The goal of the scorecard is to uncover spatial conflicts in planning policies that can increase vulnerability or hazard risk. To do this, they overlap policies that affect land use and development, social vulnerability, and hazard zones. They develop a step-by-step approach that practitioners can use when developing plans, which divides the planning development process into several tasks: (1) policy tasks: assemble the 'network of plans' and generate lists of applicable policies (those which affect spatial development and management of a community); (2) mapping tasks: determine planning districts, delineate hazard zones, and map the appropriate policies; (3) policy scoring: score policies and create tables, maps, and indexes; (4) physical vulnerability: assess and analyze physical vulnerability; (5) social vulnerability: assess and analyze social vulnerability; (6) resilience through planning: recognize policy-induced vulnerabilities to strengthen plan integration and resilience; (7) stories: learn from experiences of other communities (Berke et al., 2015; Malecha et al., 2019). This framework will be used later in this thesis to evaluate the network of plans in Rio de Janeiro, Brazil.

When using this methodology in Brazil, it is important to understand the different realities regarding planning in the country. Historically in Brazil, most actions that affect land use and development in urban environments have focused on targeted actions, such as public housing and sanitation projects funded by the federal government. Local comprehensive plans were rarely implemented because of their vagueness and unwillingness of politicians, and zoning ordinances have become the main way of organizing the territory (Villaça, 1999). Local planning has gained new importance since the City Statute was sanctioned into law in 2001. It is a federal law establishing guidelines and norms for urban policy in the country (Brasil, 2002), which gives more prominence to municipalities, in contrast to the practice during the military regime – in place from 1964 to 1984 – that established metropolitan areas as the main local authority, obfuscating municipal governments (Maricato, 2011).

The City Statute requires that any municipality with a population bigger than 20,000 people should develop a Comprehensive Plan every ten years, aimed to guide urban development and growth. The Statute states that urban land must fulfill its social function, which should be defined in the comprehensive plans. It also establishes policy tools that can foster equity and democratic governance at the local level, such as the progressive increase in property taxes for empty and underused parcels (Brasil, 2002). However, many municipalities do not have the administrative capacity to fully implement their local plans, this way the federal government provides municipalities with technical assistance (Santos Junior et al. 2011).

Ten years after the establishment of the City Statute, Santos Junior and Montandon (2011) evaluated the quality of comprehensive plans across Brazil, and if they fulfilled the goals set up in the Statute. They found that there was a relative success in the federal government's program of technical assistance since municipalities have been including many of the urban management tools established in the City Statute in their comprehensive plans. However, they also found that most plans do not have clear implementation strategies. For example, many municipalities mention the instrument of Special Zones of Social Interest (ZEIS), which are areas reserved for affordable housing development, but they do no clearly define in the plans how to operationalize this instrument or reinforce it. Additionally, there is a general lack of mappable instruments, specific goals, and timelines in the comprehensive plans across the country, and most depend on additional laws to fulfill their goals (Santos Junior & Montandon, 2011).

They also state that most plans treat environmental matters disconnected from other land use issues, many times conflicting with other policies.

> *The contradiction between this environmental approach and the urban approach is reflected alarmingly, for example, when tackling conflicts regarding social housing and regulation of informal settlements in environmentally protected areas, where answers found in the Plans are not always linked with the guarantee of the right to housing and requirement of relocation in cases where it is not possible for residents to stay, opening up the possibility for the environmental discourse to be used as justification for the removal of communities and reproduction of socio, spatial, and urban segregation*. (Santos Junior & Montandon, 2011, p.43)[2]

Maricato (2011) points to another problem which is the lack of metropolitan planning. Municipalities in the same metropolitan areas fail to develop a horizontal planning process, and a plan from one city may contradict the plans of its neighbor. This being a result of the previous practice of undermining municipal authority in favor of metropolitan (Maricato, 2011).

While researching this thesis it was difficult to find any Brazilian literature specific to plan evaluation, even though there is rich literature regarding planning and urbanism in the country. This might be due to Brazil only starting to democratically

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[2] *"A contradição entre essa abordagem ambiental e a abordagem urbana se reflete de forma grave, por exemplo, no enfrentamento dos conflitos envolvendo a questão da habitação de interesse social e a regularização de assentamentos informais em áreas de preservação, cujas respostas presentes nos Planos nem sempre estão associadas à garantia do direito à moradia e à obrigatoriedade de reassentamento nos casos em que a permanência da população não for possível, abrindo a possibilidade de o discurso ambiental ser utilizado para justificar processos de remoção e reprodução de mecanismos de exclusão socioespacial e segregação urbana." (Santos Junior & Montandon, 2011, p.43)*

develop local plans in the 1990s, or a history of plans not being implemented and being used as discourse and not practice (Villaça, 1999). Additionally, although urban policy documents contain detailed land-use strategies, such as building codes and zoning, informal urbanization that ignores these plans is widespread in all urban centers. Since the private real estate market is exclusionary, those who cannot access it have as their only alternative to occupy the unwanted areas, being exposed to a myriad of hazards. These "illegal" occupations have been largely tolerated by local governments, who generally only interfere if it is for the benefit of the private real estate market, which makes the ambiguity between formal and informal an intrinsic characteristic of Brazilian urban development (Maricato, 2003).

As it was discussed, to create resilient cities an important step is to have good local plans that focus on hazard mitigation and vulnerability reduction. Good plans should have specific goals, implementation strategies, timelines, and evaluation measures, however, to increase resilience local plans must be consistent with each other. In Brazil, local planning only started to gain strength in the early 1990s, with the City Statute consolidating their importance. This is reflected in the lack of basic elements of good quality plans in many local comprehensive plans across the country. Another challenge for local planning in Brazil is the high level of informality in urban centers, where legal and illegal are impossible to dissociate.

Social Vulnerability to Disasters

As mentioned previously, an important part of planning for resilience is to consider disaster risk and social vulnerability, and the interactions between the two (Marchezini et al., 2017a; Wisner et al., 2012). Thus, the notion that disasters are the rupture of a system could be replaced by the idea that it is a consequence of this system (Kim, 2015). Even events such as earthquakes, which are difficult for humans to have any influence on, can be locally mitigated, for example, with building-code standards and land-use legislation (Wisner et al, 2012). The understanding that disaster risk has a social component has created a shift in the disaster management paradigm. Previously it focused on four stages: preparedness, response, recovery, and mitigation, however, more recently, vulnerability and resiliency have become key components for the discussion (Kim, 2015).

Vulnerability as a concept can have different meanings depending on the field of knowledge. In DRR it is largely understood as *"the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards*" (UNDRR, n.d. b). It relates to social and environmental inequalities and uneven development, and researchers have been attempting to measure it through qualitative and quantitative approaches. While most quantitative approaches see it as a fixed characteristic of a certain portion of society, qualitative approaches generally understand it as a dynamic force (Bolin & Kurtz, 2018). Additionally, another critique about quantitative indexes is that there is a general lack of quality assessment and validation of them. Since social vulnerability is not a directly observable characteristic, researchers must rely on statistical methods to create composite indexes, risking oversimplifying a complex phenomenon (Spielman et al., 2020). However, qualitative approaches tend to be limited in scope and scale, and hard to apply in management institutions (Bolin & Kurtz, 2018). One important quantitative strategy is developing indexes, such as Cutter et al.'s (2003) Social Vulnerability Index (SoVI).

Cutter et al.'s (2003) SoVI is the most widely used quantitative index, it was first developed as a general measure of social vulnerability to environmental hazards in the USA. It compares geographic units by ranking several social-economic indicators, establishing relative levels of vulnerability where higher ranked areas have higher vulnerability. It has been cited thousands of times, adapted to international contexts, and has been used by government and non-profit institutions (Spielman et al., 2020). The current version of SoVI has twenty-nine variables that have the goal of capturing social, economic, and environmental inequalities (University of South Carolina, n.d.).

Hummell et al. (2016) have adapted SoVI to compare social vulnerability between municipalities in Brazil, many adjustments for the indicators were necessary to account for the Brazilian context and data availability. The main changes were in indicators related to socioeconomic status, race and ethnicity, and quality of the built environment, the final SoVI for Brazil has forty-six indicators. The study found that the most vulnerable municipalities are in the North and Northeast regions of the country, however, intensely populated cities like Sao Paulo and Rio de Janeiro, both in the Southeast region of the country, also presented high levels of social vulnerability (Hummell et al., 2016) (Figure 1).

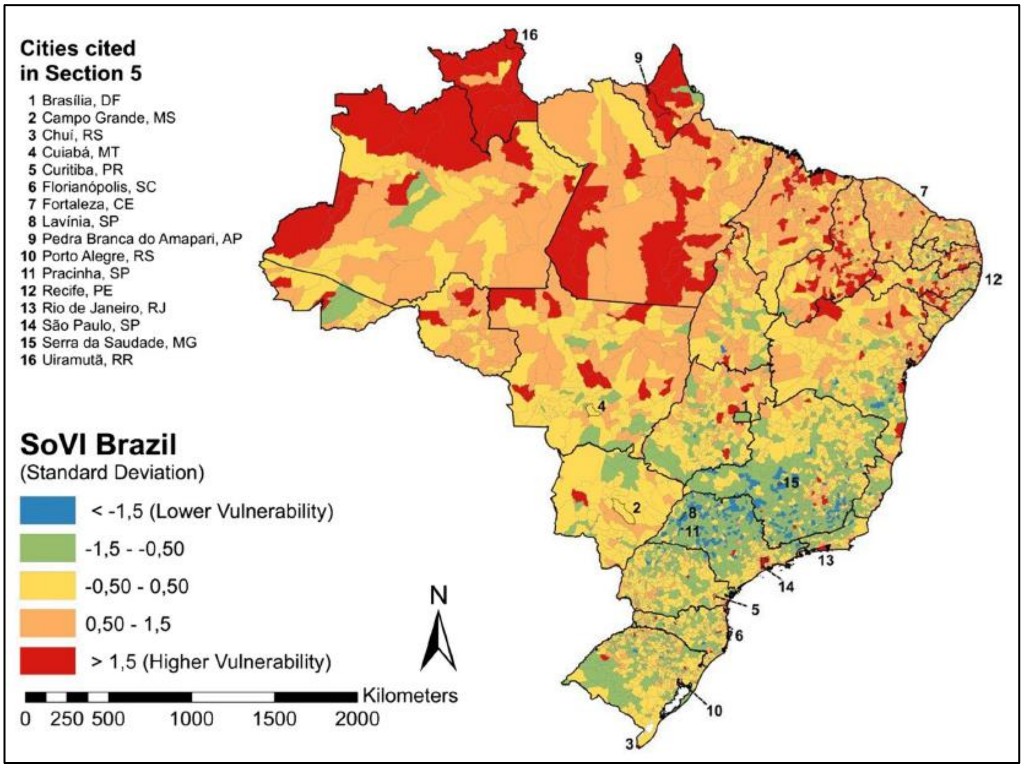

Figure 1: Map showing comparative social vulnerability index in Brazil, based on SoVI (Hummell et al., 2016, p. 121)

These findings are aligned with another effort to measure social vulnerability in Brazil. Almeida et al. (2017) developed the Disaster Risk Index in Brazil (DRIB), based on the World Risk Index, which is used by the UNDRR in the Global Assessment Report (GAR) Atlas. This evaluation is done by combining five other indexes, and for the Brazilian case was done by considering data for municipalities. They considered the following indexes: <u>exposure</u> to a certain hazard; the <u>susceptibility</u> level, meaning the probability of the exposed community to suffer damage; <u>coping capacity</u>, meaning the ability to immediately react and manage the impact of the hazardous event; the adaptive capacity in the long term, meaning the capacity to change to deal with the negative consequences of natural hazards and climate change; and the overall vulnerability as a combination of all the previous indexes except exposure (Almeida et al., 2017). The index was further validated in a second paper in 2020 (Almeida et al., 2020)

In this evaluation, the exposure index shows that big urban centers such as Sao Paulo, Rio de Janeiro, and Porto Alegre have high exposure levels to droughts, floods, and landslides. The susceptibility index shows that the North and Northeast regions, especially Maranhao state, are the most susceptible to suffer damage after an event. When evaluating the coping capacity of each municipality the index shows it is not possible to distinguish between the regions, about 20% of all the country's municipalities lack coping capacity, indicating they are unable to immediately react and manage a disaster, the worst states being Minas Gerais, and Maranhao. In the adaptive capacity index Maranhao state also stands out as not being able to adapt, as well as Piaui state, Vale do Ribeira region in Sao Paulo state, and the Agreste region. The overall vulnerability index showed that the North and Northeast regions, the north of Minas Gerais state and Vale do Ribeira region, are the most vulnerable in the country. Finally, the overall DRIB index shows the North and Northeast regions of the country with the highest risk of disasters (Almeida et al., 2020) (Figures 2 and 3). It is important to notice that, for the present research, no efforts were found that applied social vulnerability indexes in geographies smaller than the municipalities.

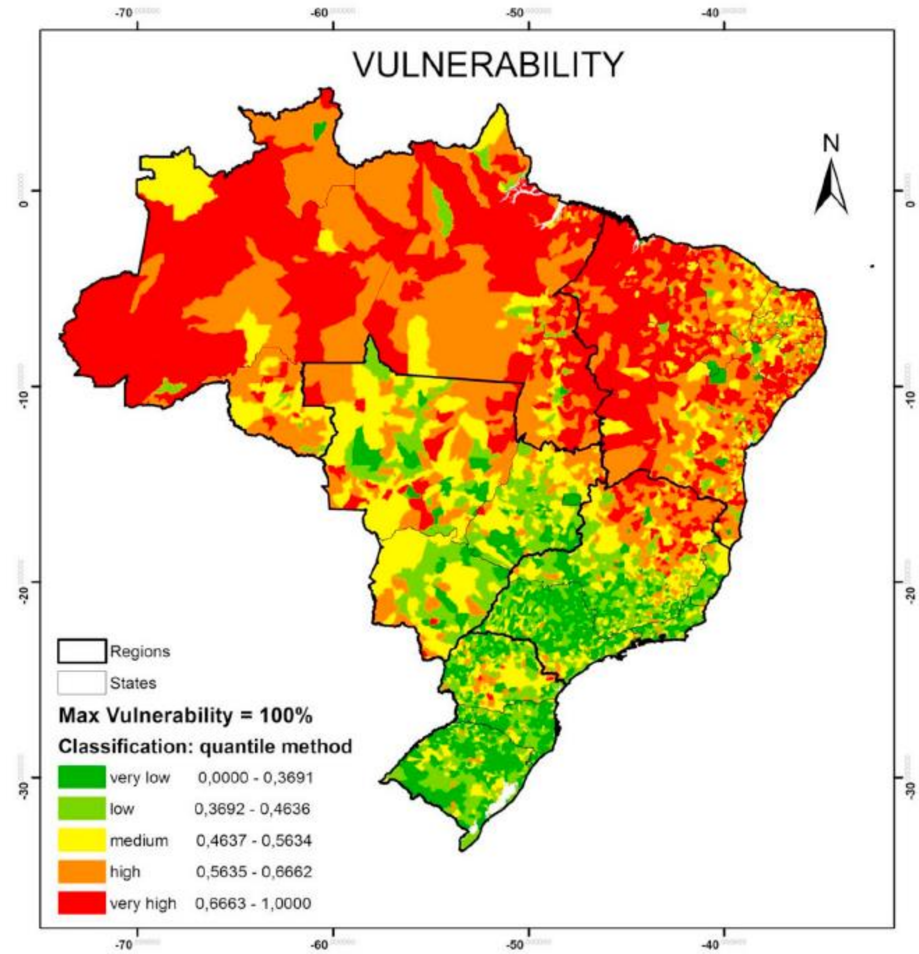

Figure 2: Vulnerability map for DRIB by municipality (Almeida et al., 2020, p. 10).

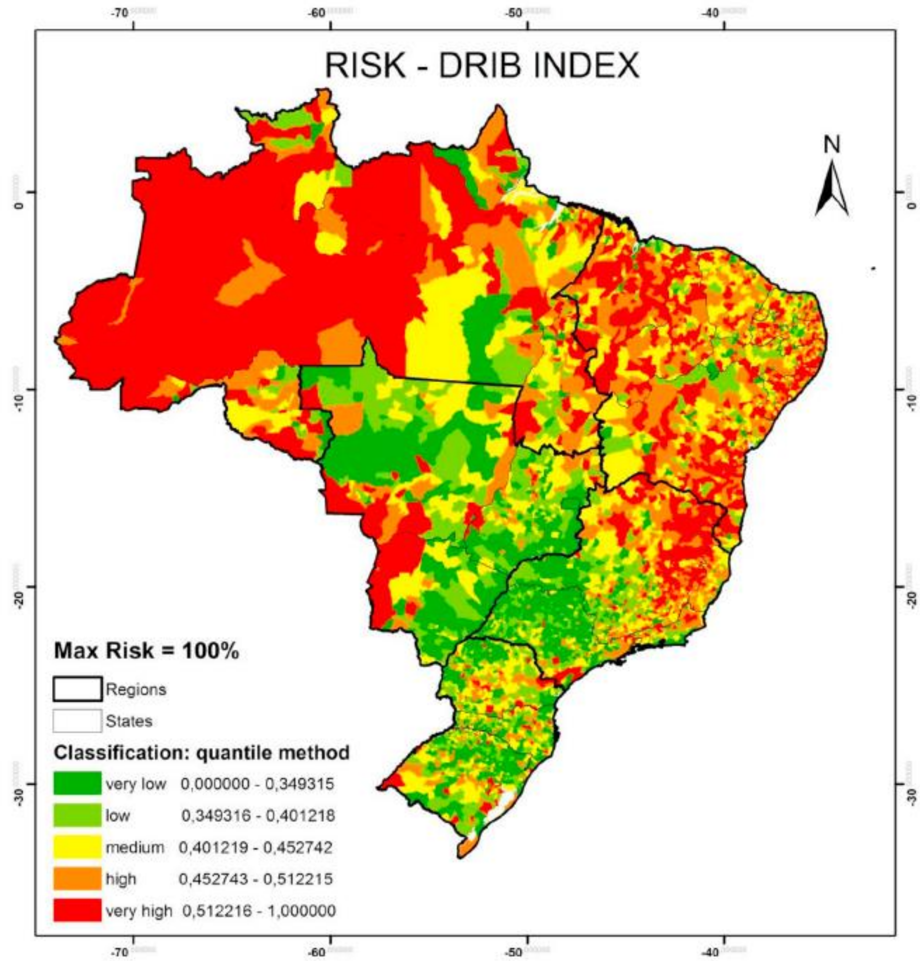

Figure 3: Overall risk map for DRIB by municipality (Almeida et al., 2020, p. 11).

However, as mentioned previously, social vulnerability indexes only account for the social conditions at a certain point in time and do not explain how the vulnerable areas came to be or why they are distributed that way. This social production of disasters is largely a result of the development model of a place[3], meaning the historic patterns that

[3] "*A development model is considered here in its broad conception, which involves the dynamics of the economic activity (production, distribution and consumption) and its regulation, the values, beliefs and collective aspirations that dictate the practical life of a society, and the rules for organization and functioning of political institutions. The different spatial scales of this social life, in which we participate at*

define a society, its economy, culture, government, etc, thus disasters can be seen as manifestations of development problems that caused conditions of vulnerability (Valencio & Valencio, 2017; Marchezini & Wisner, 2017). To better understand the causes of vulnerability a combination of many research efforts culminated into the Pressure and Release (PAR) model, which is a processual analysis of vulnerability accumulation and production of environmental inequality (Wisner et al., 2012). In this model, the *vulnerabilization*[4] process is historical and geographical, composed of root causes, dynamic pressures, and unsafe conditions (Bolin & Kurtz, 2018; Marchezini & Wisner, 2017; Wisner et al., 2012). Root causes of vulnerability involve socio-economic structures, ideologies, and historical heritage and they can be considered structural problems. Dynamic pressures are changes that occur in a few decades, such as economic cycles and population shifts. Dynamic pressures translate root causes to local scale, producing unsafe conditions (Marchezini & Wisner, 2017) (Figure 4). The PAR model will be applied to analyze the root causes of vulnerability to disasters in Rio de Janeiro.

Lastly, social vulnerability has become an essential concept when discussing disasters, it is determined by socioeconomic and environmental inequalities of a community, and caused by the development model of a place. One important way of measuring it is by using quantitative indexes, such as SoVI. Although quantitative

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different levels (individual, communitarian, national, global), are interwoven by diverse socio-environmental connection, even more complex. Some of these connections are created consensually by the involved parties. Others occur by default and might be accepted by the parties or may constitute an undesirable field of disputes." (Valencio & Valencio, 2017 p.115)

[4] "*The term 'vulnerabilization' refers not to the vulnerability as a state of a subject, but to a social relation of domination that results in precluding the dominated from any condition of self-protection*." (Valencio & Valencio, 2017 p.120)

indexes are limited, they are a straightforward way governments and institutions have to evaluate social vulnerability in their communities. There were two initiatives identified for this research that implemented social vulnerability indexed in Brazil, which identified the North and Northeast regions of the country as the most vulnerable, as well as some big urban centers such as Rio de Janeiro and Sao Paulo. However, another way of assessing vulnerability is to discuss the historical causes of vulnerability.

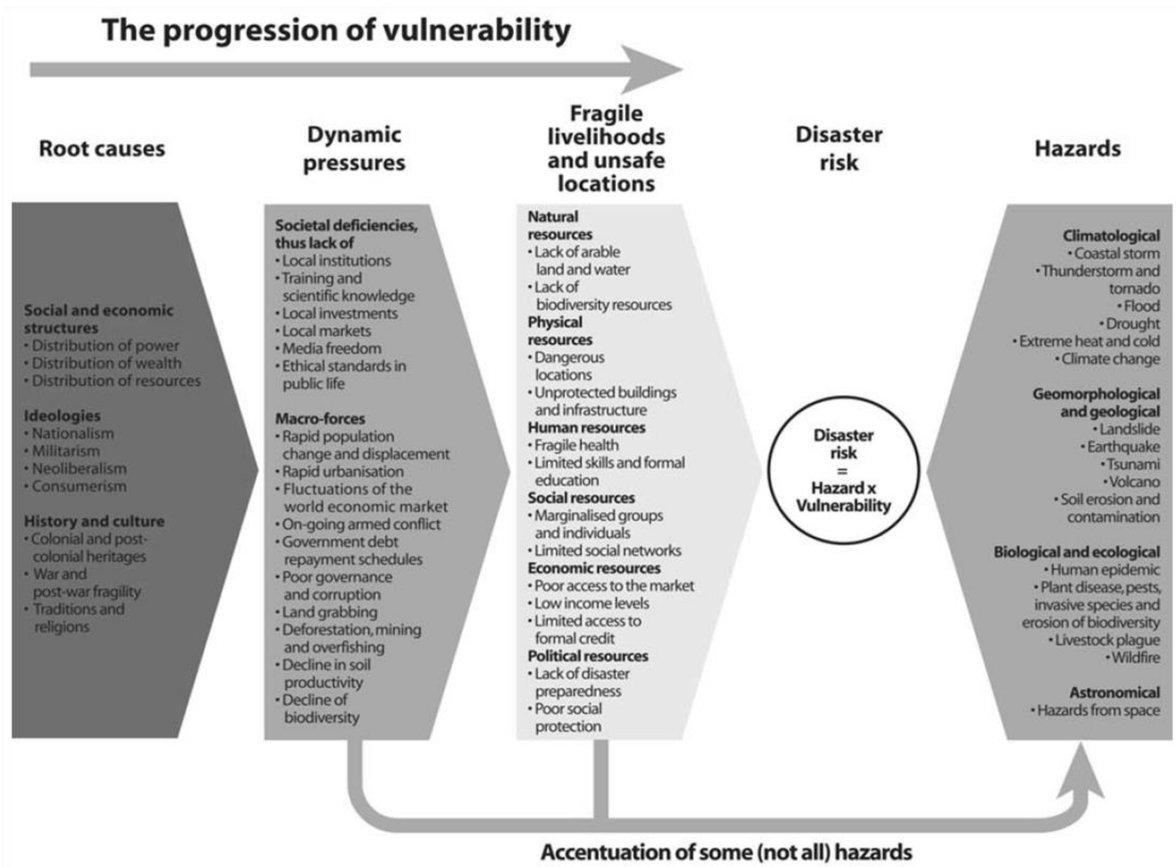


Figure 4: The progression of vulnerability for the PAR model (Wisner et al., 2012, p.23).

VULNERABILIZATION PROCESS IN THE CITY OF RIO DE JANEIRO

Rio de Janeiro is the second-largest city in Brazil, with around 6.3 million people. It was established in 1560 and since then it has played a central role in Brazil's national history as well as that of the southeastern region. It first developed as an important harbor city, and with many plantations surrounding it, it soon became an economic center for the country. It was the national capital from the 17th century until 1960, and the capital of the Portuguese empire from 1808 to 1822 (IBGE, n.d.). Because of this, Rio has a history of urban renewal projects from its foundation until more recently, when it hosted the 2007 Pan American Games, 2014 FIFA World Cup, and 2016 Olympic Games, which influenced land-use patterns (Sisson, 2008). Additionally, these factors have affected the social patterns of the city, with the historically disenfranchised population living in risk areas. The city has historically suffered from landslides related to storms, and there are recorded damage by them since the 19th century (Dereczynski et al., 2017). The problem is still present, the Department of Public Health of the city mapped landslides and floods between 2014 and 2020, and the result shows most of the city being impacted (Figure 5). Furthermore, Rio de Janeiro State had the highest material loss by disasters of any Brazilian State in the period between 1995 and 2014 (CEPED-UFSC, 2016).

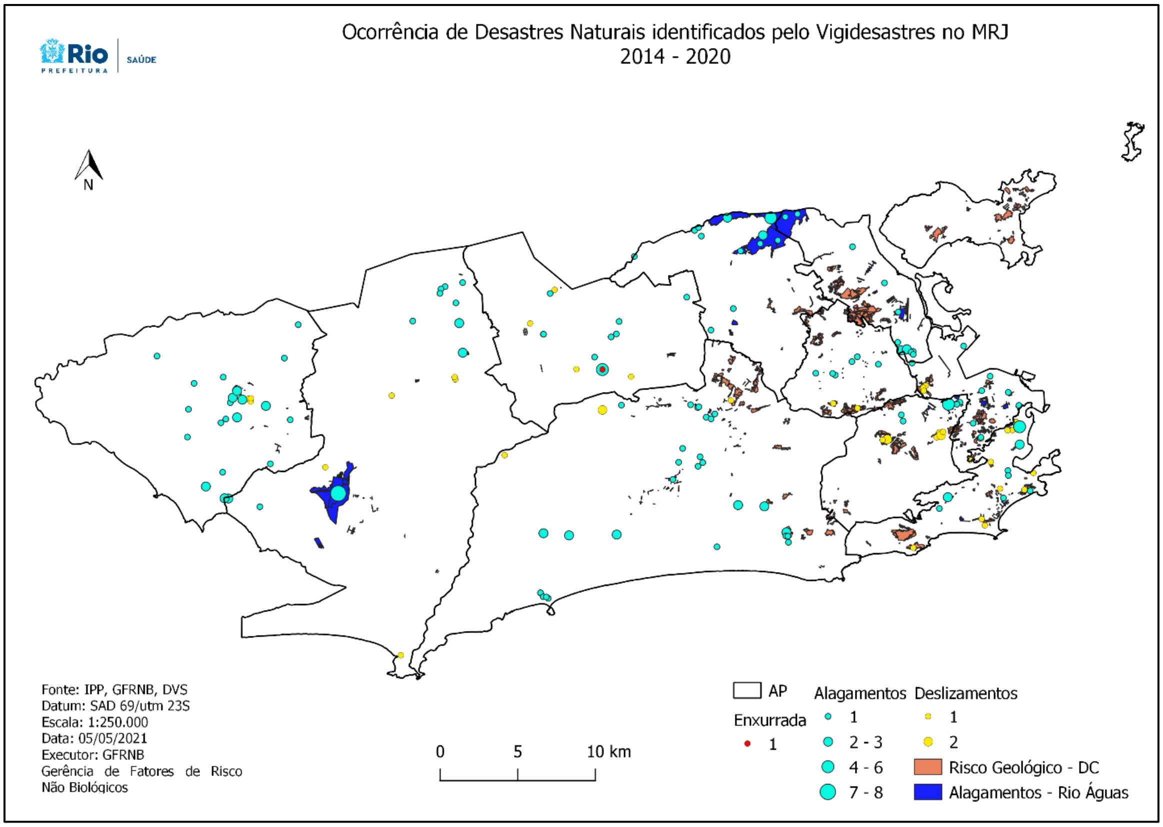


Figure 5: Natural disasters occurrences identified by Vigiadesastres in the City of Rio de Janeiro, the emergency management program from the Department of Public Health. (SMS, n.d.) (Legend translation: Enxurrada = torrent / Alagamentos = flood / Deslizamentos = landslides / Risco Geológico = geological risk / Alagamentos – Rio Águas = flooding registered by Rio Águas.)

The city, as many in the country, is characterized by extreme social segregation, with 22% of its population living in informal slums, known as favelas (Rio, 2013a). It is marked by a dichotomy of "center-periphery", in which high-income residents are concentrated in what is considered the city's center, and the periphery contains the low-income areas. These spatial and social structures have been reinforced by many local and national policies, which have generally focused on economic development while ignoring social costs, and investment goes mostly to areas that bring a good economic return – the high-income areas – which causes the center to have a concentration of public transit, services, urban infrastructure, cultural and educational opportunities, and jobs. The low-income periphery lacks many basic services and infrastructure, which reinforces segregation and vulnerabilities (Abreu, 2005). This can be exemplified by the urban projects related to the 2016 Olympic Games, where most investments went to building new infrastructure in the central areas, displacing many, and the social policies that would be implemented as compensation, such as the housing program Morar Carioca, a municipal slum-upgrading program financed with federal resources, got hamstrung after the event passed (Bienenstein & Mascarenhas, 2017).

Rio also exemplifies the national trend of institutionalized displacement of the low-income population, which is also a highly racialized matter. As pointed by Bolin & Kurtz (2018), race and class are inextricably bound up together in many countries, and Brazil is no exception. Historic racially exclusionary practices shape urban form and social relations, and racist social constructs make low-income and people of color the most affected by disasters worldwide (Bolin & Kurtz, 2018; Jacobs, 2019). This makes race an important piece to consider in the analysis of the vulnerabilization process. In Rio, half of the population is made of black and pardo people, and this population is mostly located in the favelas. However, in middle-class and high-income neighborhoods only 20% or less of the population is black (Rio, 2013a).

This is a result of how Brazil has historically dealt with people of African ancestry, especially after the abolition of slavery in 1889. The State did not provide resources for the free black people to integrate into society, which caused formerly enslaved people to be excluded from the labor market and education opportunities. Although marginalized from the ongoing modernization process of the country, the abolition led to a large-scale migration of former plantation workers to the city. This was spatially translated into them occupying steep and prone to landslides hills, which were the only areas available (Marchezini & Wisner, 2017).

The spatial segregation of low-income and black and pardo people is also reinforced by national trends. The Brazilian population went from being 30% urban to, currently, 84% urban in the last sixty years, and this process was characterized by the reproduction of unequal urban development and land use. Low-income people, which are mostly black and pardo, have long been excluded from the formal real estate market, being forced to irregularly occupy hazardous areas (Marchezini & Wisner, 2017). Furthermore, public housing policies are frequently dependent on generating profit for private developers, many times with technocratic top-down approaches that disregard quality. Several affordable housing projects have architectural problems, such as housing units being unreasonably small for families, and are often located far from services and infrastructure of urban areas (Portella & Oliveira, 2017).

In the case of Rio de Janeiro, the segregation patterns were exacerbated during the 20^{th} century. During the 1900s and 1920s period the city experienced fast population growth due to new industrialization, however, the formal housing production did not follow population growth, already forcing people to find informal housing solutions (Ribeiro, 2015a). The city, which initially occupied only the Southeast region of today's limits, started sprawling further North and East, creating middle and low-income suburbs (Leal, 2016). Already in the 1930s, the South Zone started establishing itself as a high-income neighborhood, and by the late 1950s, this area had been consolidated in local imaginary as the "developed" part of the city, with skyscrapers and cosmopolitan life, while the rest of the city was characterized by mainly low-rise developments and a lifestyle similar to small towns (Ribeiro, 2015a). In the 1960s and 1970s Brazil experience a great migration movement of rural workers moving to urban centers, which forced cities into a rapid and unregulated urbanization process (Tavares & de Oliveira, 2015). In the 1980s an economic crisis exacerbated the housing crisis, and although favelas were already present in the city since the 19th century, this decade marked their significant expansion (Ribeiro, 2015b)

Another factor that contributes to the vulnerabilization process is the different levels of institutional fragility in Brazil that are reflected in the city of Rio de Janeiro. First, there is a lack of data about disasters, as well as weak articulation between databases, making different agencies release conflicting information or even omit information, affecting the definition of policies, priorities, and even mapping products that influence decision-making (Marchezini & Wisner, 2017; Beilin & Wilkinson, 2015). As previously mentioned, natural hazard risk is different from disaster risk since the concept of disaster encompasses social elements that are not present in the idea of hazard. However, in Brazil, many agencies focus only on measuring and monitoring natural hazards, still with the interpretation that disasters are only natural phenomena (Marchezini et al., 2017a).

An additional institutional fragility is the response system, which relies on Civil Defense. This public institution was first established during the Second World War as a Brazilian contribution to promoting protection in the city of London, England, and stayed active in Brazil after the war (Londe et al., 2015). Consequently, the 1988 Brazilian constitution created the National Civil Defense System (SINDEC), officially making this institution responsible for disaster response and prevention. The system is divided into national, state, and municipal branches, where the municipal branches are tasked with most of the pre-disaster action and disaster response, and the others are responsible for responding to events only when it outstrips the municipal branch capacity (Soriano et al., 2017). However, as its origin suggests, Civil Defense deals with disasters mostly as a natural threat, and a large part of prevention measures are focused on warning systems and strategies to quickly evacuate areas during hazardous events. Many Civil Defense agents point to the lack of political will and community engagement for their shortcomings, additionally, it is common the idea between agents that populations in risk areas are the ones to blame for living in these places (Londe et al., 2015). Furthermore, the institution has no career plan, the agents are nominated by public officials, and often change with each new administration, and many of its actions are dependent on community volunteers, increasing the institutional fragility of the Civil Defense (Soriano et al., 2017).

Another vulnerabilization factor is the existing development model in Brazil, which is largely rooted in patrimonialism. This is a system where public power is dominated by private interests that control it and use it to fulfill personal demands. This translates to counter-productive bureaucracy and systemic corruption. In Brazil, the state apparatus is controlled by an alliance of elite groups, such as regional oligarchies and party leaders, which work to maintain their power positions and privileges, as well as silence and oppress those that oppose this system. This is particularly evident in the conflicts between agribusiness and environmentalists, for example (Valencio & Valencio, 2017). The city and state of Rio de Janeiro have become epitomes of patrimonialism. As of 2020 the last six state governors, including the current one, are being investigated for corruption, with one convicted. The current and former mayors of the city of Rio de Janeiro are also being investigated for corruption. Furthermore, many local politicians are known to be involved with militia groups, showing the extent of the corruption, which throttles state capacity (Gazeta do Povo, 2020).

Finally, a key vulnerabilization factor for Rio de Janeiro, which encompasses many of the previously discussed concepts, is violence, particularly relating to disputes of control over favelas. For many years this issue revolved mainly around controlling and repressing drug trafficking, and public policies have ranged from direct confront, that criminalizes poverty, to more “humanitarian” policing that controls and disciplines the “non-civilized poor” (Rocha, 2019). Although drug trafficking is still heavily present in Rio, recent events have shifted the public gaze to the action of the milícias, which currently are more feared by the local population than drug lords. These milícias are typically groups of current and former security officers, such as police and firefighters, that forcibly control a territory - normally favelas - with promises of protection and provision of services, such as cable TV, natural gas, and water. They act in capacities where the State is absent and use their control to gain economic benefits, by charging taxes and selling services, as well as to elect politicians (Benmergui & Gonçalves, 2019; Pinto, 2019).

The milícias reinforce their power by intimidation, extortion, and murder; they act in many different capacities, controlling resources and keeping relations with elites and drug lords. The first milícia emerged in 1990, in favela Rio das Pedras, on the west side of Rio de Janeiro (Pinto, 2019), however, its origins can be traced back to police practices from 1950 (Benmergui & Gonçalves, 2019; Barifouse, 2018). One key element of its activities is engaging in real estate development, which profits from informality and unsafety. The practice includes the illegal appropriation of public land, mass construction of apartment buildings, and informal financing practices. Their practices differ from the "traditional" informality of favelas by scale and logic. While the traditional model is based on self-construction to meet a family's need, in the milícias model construction happens comprehensively, focusing on maximizing profits by saving on materials and without safety concerns. Two recent cases that have become emblematic of the threats the milícias pose to society are the assassination of councilwoman Marielle Franco and her driver Anderson Gomes, and the collapse of two apartment buildings in the Muzema community (Benmergui & Gonçalves, 2019).

Rio de Janeiro is one of the most important cities in Brazil, and many of the country's contradictions are reflected in it. Many political, social, and economical forces combine to increase vulnerability to disasters in the area. In addition to the social factors, Ramos (2017) showed that Rio de Janeiro is one of the states with higher susceptibility to landslides in urbanized areas in the country. Although in her study São Paulo state is shown as having the largest amount of urban land area affected by landslides in Brazil - 3,978 km² representing 1.6% of the State's area - when adjusting proportionally to the state's size Rio de Janeiro is more affected, with 3,712 km² - 8.48% of the State's total area – being prone to landslides. The city of Rio de Janeiro is mapped, in this analysis, as one of the greatest urban areas prone to landslides.

In the city of Rio de Janeiro, it is clear that disasters are a result of rapid and unequal spatial development, discriminatory and technocratic policies that forced low-income and black and pardo people to occupy hazardous areas, institutional fragility, and patrimonialism that generates corruption and violence. This inequitable situation results in the State of Rio de Janeiro having the highest material loss by disasters in Brazil, and fatalities caused by floods and landslides are an unfortunate pattern. After analyzing the vulnerabilization process of the city, questions regarding what can be done about the issue remain. Resilience building can be one way of moving forward since it is a comprehensive approach that encompasses adaptation and mitigation strategies. However, considering the many elements that need to be tackled to create a more resilient Rio de Janeiro – such as political will and decrease in violence –, it is still unclear if this task will ever be accomplished.

Chapter 2: Methods

After the literature review, it is possible to understand that many factors need to be taken into consideration when building resilience in communities. In the past two decades, Rio de Janeiro has been making efforts to increase resilience in the city, its 2011 comprehensive plan has principles of sustainable development as guiding principles, which try to balance economic development, environmental protection, and social equity. The city also created, in 2010, Operation Center of Rio (COR), a centralized location for monitoring and managing the city's daily functions, such as traffic accidents, and weather events (COR, n.d.), they also have the system Alerta Rio, which focuses on monitoring flood and landslides (Alerta Rio, n.d.). Additionally, in 2016 they developed a plan with strategies for climate change adaptation (Rio, 2016). However, the city still suffers regularly from landslides, and fatalities are not uncommon. As recently as April of 2021 at least ten people have been displaced because of landslides (Correia et al., 2021). This raises concerns about whether the city's efforts are enough.

This research started with a few questions, first, what are the most socially vulnerable areas to landslides in the city? Also, do the most socially vulnerable areas coincide with the high-risk areas? There is a common perception that only favelas are located in landslide-prone areas, but no efforts were found that mapped social vulnerability to disasters in the city or that compared social factors with exposure to risk within the city. Additionally, another question that arose is, considering the recurring disaster losses in Rio de Janeiro, are the current local plans and policies adequately addressing landslide risk and reduction of social in the city?

One hypothesis is that the city is not adequately addressing social vulnerability to disasters, always assuming that the only action needed is to upgrade or remove favelas. Another hypothesis is that the local plans and policies do not adequately address disaster risk reduction. To answer the research questions, the process was divided into two phases, the first step was to map vulnerability in Rio de Janeiro, and the second was to rate the policies from the city. To map social vulnerability to disasters in Rio, it was necessary to select an existing social vulnerability index, adapt it to Rio's context, and compare it with risk to landslides across the city. After mapping vulnerability and risk the evaluation of local policies was done based on their ability to reduce social vulnerability.

DEFINING INDICATORS

The first step to map social vulnerability in Rio was to find which index would be most suitable for mapping social vulnerability within city limits. In Brazil, there are three levels of government, federal, state, and municipal, and the Brazilian Institute of Geography and Statistics (IBGE), the one responsible for the Census, divides the municipalities into smaller geographies for statistical purposes. The smallest geography in the Brazilian Census with publicly available data is the Census Sector, in urbanized areas a Sector can be made up of 250 to 400 households, in non-urbanized areas a Sector is made up of 150 to 250 households. Sectors are combined to form Subdistricts, then Districts, which form the municipality. Sectors can also be combined to form Weighting

Areas, which provide sample statistics (IBGE, 2013). It is important to notice that all geographies are within one another, meaning a Census Sector will only be part of one Subdistrict and so on, also, in Rio de Janeiro, Weighting Areas and Subdistricts have the same boundaries, although they have different identification codes.

Four indexes that could be used were found, however, it is important to notice that, because social vulnerability is not an observable characteristic in itself but a combination of factors, all indexes present some level of uncertainty. To decide which one to use for the current work, the main factors considered were data availability, suitability of indicators to the Brazilian context, and the ability to reproduce it. The first indicator selected was the DRIB Index developed by Almeida et al. (2020), already mentioned in the previous chapter, it uses twenty-one indicators, combining them into five indexes. Although DRIB is a comprehensive index and developed specifically for the Brazilian context, many of its indicators are only available at the municipal level. This way, it would not be possible to reproduce it for geographies smaller than the municipality.

The second index considered for analysis was the Social Vulnerability Index (IVS) developed by Brazil’s Institute of Applied Economics Research (IPEA). This index is based on the Human Development Index and uses 16 indicators divided into three categories: urban infrastructure, human capital, and job and income (Costa & Marguti, 2015). It has the advantage of being available for consultation online at a scale smaller than the municipality, however, it is not a geographic division used by IBGE. One important downfall, however, was that it focuses mainly on economic factors, having indicators that were not the most relevant for evaluating social vulnerability to disaster (IPEA, n.d.; Costa & Marguti, 2015).

The other two indexes evaluated were the SoVI Brazil by Hummell et al. (2016), and the Social Vulnerability Index (SVI) developed by the Centers for Disease Control and Prevention (CDC) (Flanagan et al., 2011). For the present work, both indexes were suitable to analyze social vulnerability in Rio, SoVI Brazil was first developed using data for the municipal level, and many of the indicators are also available at smaller geographies. However, the SoVI methodology was too complex to be reproduced in the context of this thesis, which made SVI the best option for analyzing social vulnerability in Rio. There was no work found where SVI was applied to the Brazilian context, this way SoVI Brazil was used as a reference to adapt some of the SVI indicators to make them more adequate to the Brazilian context.

The SVI uses 15 indicators, divided into four categories: “socioeconomic status”, “household composition and disability”, “minority status and language”, “housing type and transportation” (Figure 6). For the present work the categories for “housing type and transportation”, and “minority status and language” were the ones requiring the most changes.

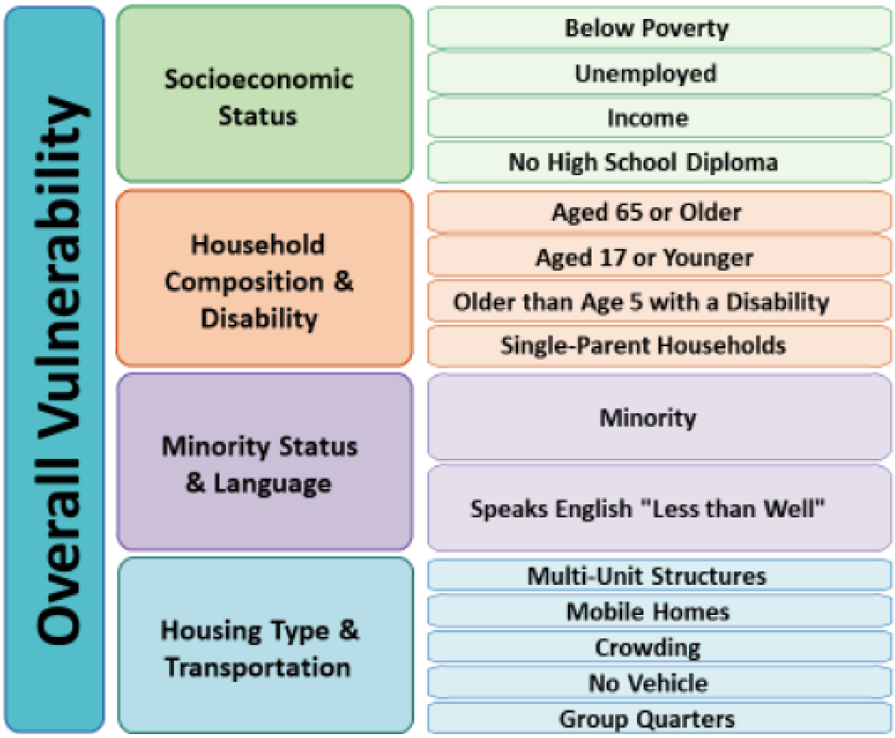


Figure 6: SVI indicators (CDC, 2020, p.3)

The index combines multiple characteristics that indicate a community might be more susceptible to be adversely impacted by an environmental hazard. The "socioeconomic status" category has the goal of accounting for economically disadvantaged populations, which are disproportionately affected by disasters and normally do not have the resources to prepare and recover from them. The "household composition and disability" group aims to account for people who are more likely to require financial support or assistance with daily activities and may have difficulties protecting themselves during a disaster. The "minority status and language" category accounts for the historic marginalization of certain racial groups that makes them inherently more vulnerable to disasters, additionally, language barriers may increase vulnerability since communication capacity is essential during a disaster. Finally, the “housing type and transportation” category aims to account for the physical vulnerability of specific structures, as well as the ability to evacuate a location promptly (Flanagan et al., 2011).

The first step to adapt the SVI to the Brazilian context was to evaluate each indicator for its suitability. Most indicators for “socioeconomic status”, and “household composition and disability” had equivalent categories in the Brazilian Census. The only indicator in these categories that needed adaptation was “male or female householder, no spouse present, with children under 18”, although IBGE collects this information it only makes it publicly available at the municipal level, however, it does provide, by Census Sector, the number of offspring living in each household. This way, for Rio’s SVI this indicator, was substituted for “children only of the head of the household, below 18 years old, by the total number of offspring”, meaning the number of kids living with only one biological parent. Although this does not exactly represent single-parent families, since it does not account for step-parents, it was the best proxy at the Census Sector level.

For the category “minority status and language”, the first indicator adapted was minority population. Contrary to the United States, the Brazilian race definitions are not based on place of origin, IBGE categories are defined mostly based on skin color, with the only exception being the category for the indigenous population. For the Brazilian Census, people can self-identify as White, Black, Pardo (Brown), Yellow (Asian), or Indigenous (Petruccelli & Saboia, 2013). The latest data shows that the country is made up of 43% White, 47% Pardo, 9% Black, and 1 % Asian or Indigenous (IBGE Educa, n.d.), this way in the making of the SVI for Rio, all race categories were included in the index except White since it has a negative correlation to the other race categories and does not represent higher vulnerability. The percentage for each category was calculated at the Census Sector level. The second indicator to be adapted in this category was English proficiency. There is no data in the Brazilian Census regarding Portuguese proficiency, the closest indicator is literacy rate, this way, for Rio's SVI the indicator used was the percentage of the population above fifteen years old that is illiterate.

For the category "housing and transportation" there were more considerable changes. There are significant differences between the built environment and development patterns between the United States and Brazil, and these differences are reflected in the Census data collected in each country. This way, to translate this group of indicators the focus was on the Census categories that relate to the built environment, following Hummell et al.'s adaptations for the SoVI Brazil (Hummell et al., 2016), the only indicator that was kept the same was "group quarters". For the category "no vehicle" it was only considered car ownership, with the indicator being "percentage of households without a car". Although the Census also estimates motorcycle ownership, it was not possible to assess if a household had only a motorcycle, or a motorcycle and a car, and since no Sector had more than 20% of motorcycle ownership but most had more than 20% of car ownership, car ownership was chosen as an indicator. The other built environment categories included were, households not served by the water utility company, households with open sewer, households without trash collection, households with inadequate wall materials (wood frame, reclaimed wood, adobe, or straw), and inadequate households. For the Brazilian Census, inadequate households are those that lack all of the following: two or fewer people per bedroom, it is served by the water system, it is served by the sewer system, has trash collection.

Below are the final indicators for Brazil's SVI (Figure 7):

SVI - Brazil	
Categories	**Indicators**
Socioeconomic Status	People Living Below Poverty
	Unemployed
	Per Capita Income
	People With Less Than a High School Diploma
Household Composition and Disability	Age 60 or Older
	Age 14 or Younger
	Older Than 5yo with a Disability
	Children Below 18yo living with only one parent
Race and Language	Black
	Asian
	Brown
	Indigenous
	Illiterate above 15
Built Environment	Inadequate Housing
	Not Serviced by Water Utility Co
	Open Sewer
	Not Serviced by Trash Utility Co
	No Car
	Wall Quality
	Group Quarters

Figure 7: Final indicators for SVI for Brazil

MAPPING VULNERABILITY

The Social Vulnerability Index for Rio de Janeiro was calculated for the Census Sector level, using CDC's methodology. The most updated Census data to date was used, which is the Census 2010. Because of the COVID-19 pandemic and budget cuts, the Census 2020 was delayed and there is currently no expected date for it to occur (Barros, 2021). One of the main challenges to mapping the indicators was that the data was available in two different geographies. Most data was available at the Census Sector level, however, data for unemployment, people with disabilities, wall materials, educational attainment, and car ownership was only available at the Weighting Area level. The percentages for each indicator were calculated at the geographic level they were available at, and later the indicators available only at the Weighting Area level were projected into Census Sectors. Since most indicators were obtainable at the more detailed level, projecting the Weighting Area indicators into the Census Sectors makes the analysis more precise and gives more detailed data. Census Sectors with no data were excluded from the analysis.

After eliminating null Sectors, it was possible to calculate the percentile rank of each indicator, following the method developed by the CDC (Flanagan et al., 2011). Each variable was ranked from highest to lowest, for example, higher percentages of the unemployed population had a higher ranking. The only exception was per capita income, which was ranked from lowest to highest since lower-income indicates more vulnerability. With this method, the Sectors are compared to each other, and the higher scores indicate higher vulnerability. After calculating indicators, the index for each of the categories was done by calculating the percentile rank of the sum of the ranks of each indicator. For example, the index for socioeconomic status was produced by summing up the ranks of each of the indicators of that category (people living below poverty, unemployment rate, per capita income, and people with less than a high-school diploma) and calculating the percentile rank of that sum. For the general vulnerability index, the same process was done by summing up all the indicators. Additionally, Sectors that were above the 90th percentile were flagged, facilitating the recognition of high vulnerability Sectors (Flanagan et al., 2011).

RELATING RISK AND VULNERABILITY

With social vulnerability for the city of Rio de Janeiro mapped, it was necessary to evaluate how vulnerability related to landslide risk. The map for landslide risk in Rio is available for consultation at the open data portal Data.Rio (2015), but to have access to the Shapefile it was necessary to make a formal request to the municipal geological service of Rio de Janeiro (GeoRio). The map shows the susceptibility of landslides, it combines geological, topographic and soil characteristics, and development patterns. The map shows three risk zones, low, medium, and high susceptibility. The map was first published online in May 2015 (Data.Rio, 2015).

The next step was to calculate the risk for each Census Sector. Since the risk map only had three categories to calculate the relationship between risk and vulnerability a binary classification was done, with risk zones being classified as 0 or 1. Two groupings were done, first, the zones for medium and high risk were combined, with low risk classified as 0, and both medium and high-risk areas classified as 1. Later the same process was reproduced but with low and medium risk being classified as 0 and high-risk classified as 1. Using Tabulate Intersection function in ArcGIS it was possible to get the percentage of the area of each Census Sector that was in each of the susceptibility zones. This made it possible to calculate correlations between risk and vulnerability. The correlation between SVI and risk was calculated using Pearson's correlation. A first analysis was done with Sectors that had 90% or more of their area in the medium and/or high-risk zones, and a second analysis used only Sectors that had 90% or more of their area only in the high-risk zone. The analysis considered a 95% confidence interval.

PLAN EVALUATION

The second part of this study was to evaluate the city's plans and policies in their ability to reduce vulnerability. To do that the method developed by Berke et al. (2015) and further refined by Malecha et al. (2019) to evaluate plan integration for resilience was used. The researchers developed the Plan Integration for Resilience Scorecard, which has the goal of revealing spatial incongruities in planning policies by overlaying planning districts and hazard zones (Malecha et al., 2019).

The City of Rio has many administrative divisions with the goal of organizing the territory, the smallest administrative division is the neighborhood, which mostly follows cultural definitions. Neighborhoods are combined to form Administrative Regions (RA), which are combined to form Planning Areas (AP). It is important to notice that Census Sectors respect neighborhood limits, so neighborhoods can also be defined as a combination of Census Sectors, and for the City of Rio, neighborhoods and Census Weighting Areas have the same boundaries. Although RAs and APs are used in planning activities, most plans and policies use neighborhoods as their main geography. This way, for the plan evaluation part of this thesis, neighborhoods were chosen as the geography of analysis, and APs are used as geographic reference. Since risk is not equally distributed among neighborhoods, the ArcGIS tool Tabulate Intersection was employed again, and the percentage of the area in high-risk zones of each neighborhood was calculated, the twenty neighborhoods with the most area in the high-risk zone were selected.

The next step was to select the plans and policies that would be evaluated. Following Malecha et al.'s (2019) guidelines, only policies and plans that had mappable elements with explicit impacts on development patterns and landslide risk were selected. It is important to notice that, although the city has a contingency plan for natural disasters (Rio, 2018) and a climate change adaptation plan (Rio, 2016), and the state has an emergency plan (Defesa Civil, 2020), those are only programmatic and do not have mappable elements, this way they were not included in the evaluation. The plans were all available online, and the most recent version of each was used. The policies evaluated were:

- From the Comprehensive Plan for Sustainable Urban Development of the Rio de Janeiro Municipality (Município do Rio de Janeiro, 2011): Macrozones;
- Land Use and Zoning policies: Zoning (Data.Rio, 2019g; Município do Rio de Janeiro, 1978; Município do Rio de Janeiro, 1981a; Município do

Rio de Janeiro, 1981b; Município do Rio de Janeiro, 1985; Município do Rio de Janeiro, 1987; Município do Rio de Janeiro, 1988; Município do Rio de Janeiro, 2004; Município do Rio de Janeiro, 2009), Floor Area Ratio (FAR) (Município do Rio de Janeiro, 2011), and Centralities (Rio, n.d.);

- From the Municipal Plan for Conservation and Recuperation of the Atlantic Rainforest of Rio de Janeiro: Conservation Areas (Rio, 2015; Data.Rio, 2018a);
- Location of Civil Defense Sirens (Data.Rio, 2018c);
- Location of developments from the housing programs: Favela-Bairro (Rio, 2003; Duren & Osorio, 2020), Minha Casa Minha Vida and Casa Verde Amarela (Data.Rio, 2020b; Rio, n.d.), and Morar Carioca (Rio, n.d.; Data.Rio, 2020c).

The Comprehensive Plan defines four Macrozones for the city and sets specific development guidelines for each. The Macrozones are: (I) <u>Controlled Occupation</u>, where the increase in density and development will be limited, giving preference to reconstruction or retrofits, respecting the capacity of current infrastructure; (II) <u>Stimulated Occupation</u>, where the increase in density and development will be incentivized, and large scale infrastructure projects will take place; (III) <u>Conditioned Occupation</u>, where the increase in density and development will be conditioned to the current infrastructure capacity and environmental protection; (IV) <u>Assisted Occupation</u>, where the increase in density and development will be associated with public investment in infrastructure and environmental protection measures (Município do Rio de Janeiro, 2011, Art.32). The Comprehensive Plan also establishes goals for each Macrozone, such as favela upgrading or improvement of transit infrastructure. Macrozones are important for landslide risk because they define growth patterns, and areas of high landslide risk should not be incentivized to develop.

The second policy chosen from the Comprehensive Plan is the Floor to Area Ratio (FAR) by neighborhood. The FAR is a number that defines the maximum size of a construction in a specific parcel, when multiplying the FAR by the area of the parcel the result will be the built area that is allowed. For example, in a parcel of 2,000 sq ft with FAR of 2, the final construction can have at most 4,000 sq ft (Rio, 2013c). In essence, the FAR defines the building density for a neighborhood. Areas of high risk of landslides should be kept at low density to avoid loss of life or property. The city also establishes standards for building height and setbacks, but these are defined parcel by parcel, and not at a neighborhood level (Rio, 2013c).

Besides FAR, another important land-use policy is zoning. Zoning defines the uses allowed in each area, and in Rio, all zoning categories allow for residential development, except areas with heavy industrial uses and environmentally protected areas. Considering best practices, no development should be allowed in areas of high risk of landslides, however, if development is allowed it should be low-density, such as agricultural uses or low-rise detached constructions, avoiding slope destabilization and minimizing potential losses. It is important to notice that, although there were proposed ordinances that defined land use and zoning for the entire city, these were never approved (Rio, 2013c), and currently there is no complete plan for land use and zoning in the city, but a combination of laws that were put in place at different times. This way, some neighborhoods have zoning ordinances dating back to 1978, while others have ordinances from 2009. The city does have an interactive map where it is possible to consult the city's zones, as well as the valid land-use laws for a specific parcel (Rio, n.d.). The city also makes available for download shapefiles with the current zoning (Data.Rio, 2019g).

The other two land-use policies selected for evaluation were centralities (Município do Rio de Janeiro, 2011; Rio, n.d.) and conservation areas (Rio, 2016). Centralities are the neighborhoods' centers, where there is a concentration of commercial uses, services, and transit. One of the overarching guidelines from the city's Comprehensive Plan is to further develop current centralities and incentivize the development of new ones (Município do Rio de Janeiro, 2011, Art.10). Neighborhood centers are important to disperse development and job opportunities to multiple areas of the city, not only downtown, reducing commuting times and traffic, and improving the quality of life of communities. However, since they bring development and density, they should not be stimulated if located in landslide risk areas.

The final land use policy selected was conservation areas, which are zones of strict environmental protection, they are defined by a combination of federal, state, and municipal laws (Rio, 2015). Conservation areas have rigorous regulations prohibiting any development, and although the focus is on protecting natural environments, they also protect against landslides since human intervention can cause deforestation and slope destabilization, which increases the risk of landslides (Nadim, 2017).

Although the Civil Defense plans are mostly programmatic, the location of emergency sirens is available for download on Rio's open data portal (Data.Rio, 2018d). The siren system is activated when heavy rains have the potential of causing landslides, and residents are trained to evacuate to appropriate shelter locations (Defesa Civil, 2020). This way, the location of the civil defense sirens also indicates that the residents have received emergency evacuation training.

Finally, it was also evaluated the location of the public and affordable housing developments around the city. It is important to evaluate if the city is actively considering environmental risks when making this type of development. When upgrading a favela or building new housing the city is consolidating the occupation of a certain area, possibly inviting further development. The four programs considered are from the last twenty years. The program Favela Bairro was a municipal initiative aimed at upgrading the infrastructure in favelas and bring services, its first phase ran from 1994 to 1999, and the second phase from 2000 to 2008. The program Minha Casa Minha Vida and Casa Verde Amarela are related federal financing programs aimed at making housing accessible for low-income families. The program Morar Carioca, mentioned in Chapter 1, is the most recent municipal program of favela upgrading, it was launched in 2010 and had the goal of upgrading all of Rio's favelas by 2020 (Paes & Magalhães, 2010), however, it did not achieve this goal (Bienenstein & Mascarenhas, 2017). All these programs are essential to address the housing-related and development issues in the city, however, their location should be carefully evaluated as to not locate already vulnerable populations in risk areas.

After selecting the mappable policies of different plans they were contrasted with the risk map. The policies that would increase vulnerability in risk areas received a score of -1, and those which decrease vulnerability received a score of +1. When the policy did not apply to a neighborhood a score of 0 was given. For Macrozones a +1 was given if it was a high-risk neighborhood in a Macrozone that limited development, and -1 if it incentivizes development. For Zoning, a -1 score was given when high-risk areas had zoning classifications that allowed development denser than low-rise detached units. When considering FAR, neighborhoods that had FAR of 1.5 in high-risk zones, or more than 1 in environmentally protected areas, were given -1. When analyzing the Centralities, a -1 was given when they coincide with high-risk areas. For the Conservation Areas, a -1 was given when the zones of strict protection did not include the high-risk areas or when it did not match with the 100m level curve. When evaluating the location of sirens, a +1 was given when sirens were located in high-risk areas, and -1 when there were no sirens in high-risk areas. Finally, when analyzing the location of affordable housing, -1 was given when the development was located in high-risk areas, +1 when it was located outside a high-risk area, and 0 if there were no affordable housing developments.

Some of the limitations for the plan evaluation were that only plans available online were evaluated, even though the city has a good online repository of plans and policies, some complementary plans mentioned in the Comprehensive Plan were not found. This raises questions if those tools were never developed or if they are simply not available online. Another limitation for plan evaluation is that this is an individual work, this way there was no team to validate the scores.

Chapter 3: Results and Analysis

SOCIAL VULNERABILITY AND RISK IN RIO

Mapping the Social Vulnerability Index

The first issue found when mapping social vulnerability was how to visualize risk areas and vulnerability in the same map, since the SVI maps and the Susceptibility to Landslides map are both visually complex, the 100m level curve for the city was used as a proxy for higher risk areas since it has a strong correlation with high-risk areas. As it is possible to see in Map 1, there is a strong correlation between the 100m level curve and the areas with a high risk for landslides.

The SVI for Rio compares Census Sectors within the city between each other, this way Map 3 shows the overall Social Vulnerability Index for the city of Rio de Janeiro, and Table 1 and Table 2 compare the number of Sectors in each vulnerability class. As it is possible to see, AP5 and AP1 have a great concentration of Census Sectors with very high and high vulnerability scores, with 66% of AP5's Sectors, and 51% of AP1's Sectors, being classified as high and very high vulnerability. AP4 and AP3 have a mix of Sectors of all classes of vulnerability, with AP4 having 52% of its Sectors classified as low or very low vulnerability, and AP3 having 70% of its Sectors in the intermediary classes. AP2 has the lowest concentration of Sectors with high or very high social vulnerability, with 81.5% of its Sectors classified as low or very low vulnerability.

It is important to notice that AP2 represents only 19% of the total Sectors in the city, however, it has 55% of all Sectors classified as very low vulnerability. AP5 is on the opposite side of the spectrum, with 26% of the total Sectors in the city, but 46% of all Sectors that are classified as very high vulnerability. Additionally, as it is possible to notice on Map 3, in all APs there is a concentration of Sectors of high or very high vulnerability along the 100m level curve. The pattern shown for overall SVI follows what was discussed in the literature review, that the slopes of the city of Rio were occupied by disenfranchised residents. However, high and very high vulnerability Sectors are also found in areas of the city without risk.

Table 1: Comparison of the Number of Sectors in Each Overall Social Vulnerability Classes by Planning Area

SVI	Planning Areas									
	1		2		3		4		5	
Very Low	26	4.5%	1129	57.5%	427	11.5%	420	32.0%	45	1.7%
Low	103	18.0%	471	24.0%	928	25.0%	263	20.0%	281	10.5%
Average	150	26.2%	170	8.7%	904	24.3%	232	17.7%	591	22.1%
High	146	25.5%	130	6.6%	778	20.9%	186	14.2%	806	30.2%
Very High	148	25.8%	62	3.2%	677	18.2%	211	16.1%	949	35.5%
Total Sectors	**573**	**100.0%**	**1962**	**100.0%**	**3714**	**100.0%**	**1312**	**100.0%**	**2672**	**100.0%**

Table 1: Comparison of Census Sectors by Overall SVI Classes by AP.

Table 2: Comparison of the Number of Sectors in Each Overall Social Vulnerability Classes by Planning Area and Citywide

SVI	Planning Areas											
	1	% city	2	% city	3	% city	4	% city	5	% city	Total Sectors	
Very Low	26	1.3%	1129	55.2%	427	20.9%	420	20.5%	45	2.2%	2047	100.0%
Low	103	5.0%	471	23.0%	928	45.4%	263	12.9%	281	13.7%	2046	100.0%
Average	150	7.3%	170	8.3%	904	44.2%	232	11.3%	591	28.9%	2046	100.0%
High	146	7.1%	130	6.4%	778	38.0%	186	9.1%	806	39.4%	2047	100.0%
Very High	148	7.2%	62	3.0%	677	33.1%	211	10.3%	949	46.4%	2047	100.0%
Total Sectors	**573**	5.6%	**1962**	19.2%	**3714**	36.3%	**1312**	12.8%	**2672**	26.1%	**10233**	100.0%

Table 2: Comparison of Census Sectors by Overall SVI Classes Citywide.

After mapping the overall SVI it was important to also map the individual categories. Map 4 and Tables 3 and 4 show the socioeconomic category. In this category, it is possible to notice a big contrast between APs, with AP5 having the highest concentration of Census Sectors with high or very high socioeconomic vulnerability, with 78% of its Sectors being in one of these two classes. Additionally, AP5 has 58% of all city's Sectors classified as very high Socioeconomic vulnerability, and 44% of all city's Sectors classified as high socioeconomic vulnerability, despite having only 26% of the total number of Sectors in the city. Again, AP2 has most of its Sectors with low and very low socioeconomic vulnerability, with 89% of its Sectors in one of the two categories. Also, AP2 has 70% of all city's Sectors classified as very low socioeconomic vulnerability. AP4 does not have such a stark difference in the numbers of Sectors in each class, however, it also has a concentration of Sectors of low and very low socioeconomic vulnerability in the coastal area, with the inland areas having higher vulnerability. AP3 and AP1 have a more balanced distribution of Sectors of all vulnerability categories, although not many are classified as having very low socioeconomic vulnerability in neither areas. These results for socioeconomic factors are not surprising since it reflects the common knowledge about the city, where AP2, known as the South Zone, and the coastal area of AP4, where the Barra da Tijuca neighborhood is, are well-known for being the high-income areas, and AP5, the West Zone, known for being lower income. However, the glaring difference in quantities represents the historic pattern of exclusion of low-income people having to locate in areas far from the center. Additionally, for this category, there are no clear patterns of concentration of vulnerability along the 100m level curve, except on AP2, where the most vulnerable Sectors are located alongside it.

Table 3: Comparison of the Number of Sectors in Each Socioeconomic Vulnerability Classes by Planning Area										
Socioeconomic	Sectors by Planning Areas									
	1		2		3		4		5	
Very Low	38	6.6%	1407	71.7%	214	5.8%	379	28.9%	1	0.0%
Low	200	34.9%	347	17.7%	1022	27.5%	375	28.6%	101	3.8%
Average	117	20.4%	101	5.1%	1072	28.9%	265	20.2%	491	18.4%
High	135	23.6%	74	3.8%	741	20.0%	204	15.5%	895	33.5%
Very High	83	14.5%	33	1.7%	665	17.9%	89	6.8%	1184	44.3%
Total Sectors	**573**	**100.0%**	**1962**	**100.0%**	**3714**	**100.0%**	**1312**	**100.0%**	**2672**	**100.0%**

Table 3: Comparison of Sectors by Socioeconomic Vulnerability Classes by AP.

Table 4: Comparison of the Number of Sectors in Each Socioeconomic Vulnerability Classes by Planning Area and Citywide												
Socioeconomic	Sectors by Planning Areas (citywide comparison)											
	1	% city	2	% city	3	% city	4	% city	5	% city	Total Sectors	
Very Low	38	1.9%	1407	68.8%	214	10.5%	379	18.5%	1	0.0%	2046	100.0%
Low	200	9.8%	347	16.9%	1022	49.9%	375	18.3%	101	4.9%	2049	100.0%
Average	117	5.7%	101	4.9%	1072	52.4%	265	13.0%	491	24.0%	2045	100.0%
High	135	6.6%	74	3.6%	741	36.1%	204	9.9%	895	43.6%	2054	100.0%
Very High	83	4.1%	33	1.6%	665	32.6%	89	4.4%	1184	58.1%	2039	100.0%
Total Sectors	**573**	**5.6%**	**1962**	**19.2%**	**3714**	**36.3%**	**1312**	**12.8%**	**2672**	**26.1%**	**10233**	**100.0%**

Table 4: Comparison of Sectors by Socioeconomic Vulnerability Classes Citywide.

Map 5 and Tables 5 and 6 show the household vulnerability category of the SVI, in it, the Census Sectors of high and very high vulnerability seem to have a more equivalent distribution throughout the city. AP1 and AP5 have most of their Sectors classified as high and very high household vulnerability, with 57% of AP1's Sectors, and 61% of AP5's Sectors being in these classes. For the household vulnerability, AP5 again concentrates the Sectors with very high vulnerability, having 48% of all city's Sectors in this class. In this category, AP2 and AP4 have a concentration of low and very low household vulnerability, however, in this case, AP4 has a bigger share of low and very low household vulnerability than AP2, with 70% of its Sectors classified as such, and AP2 having 63% of its Sectors in these categories. AP4 contains 29% of all city's Sectors classified as very low household vulnerability despite having only 13% of all Sectors. Although there seems to be no pattern in the location of high and very high household vulnerability Sectors in APs 1, 3, and 5, it is possible to notice that on AP2 and AP4 they are located alongside the 100m level curve.

Table 5: Comparison of the Number of Sectors in Each Household Vulnerability Classes by Planning Area

Household	Sectors by Planning Areas									
	1		2		3		4		5	
Very Low	45	7.9%	669	34.1%	510	13.7%	592	45.1%	232	8.7%
Low	79	13.8%	566	28.8%	764	20.6%	327	24.9%	310	11.6%
Average	113	19.7%	385	19.6%	889	23.9%	173	13.2%	491	18.4%
High	148	25.8%	245	12.5%	875	23.6%	114	8.7%	663	24.8%
Very High	188	32.8%	97	4.9%	676	18.2%	106	8.1%	976	36.5%
Total Sectors	**573**	**100.0%**	**1962**	**100.0%**	**3714**	**100.0%**	**1312**	**100.0%**	**2672**	**100.0%**

Table 5:Comparison of Sectors by Household Vulnerability Classes by AP.

Table 6: Comparison of the Number of Sectors in Each Household Vulnerability Classes by Planning Area and Citywide

Household	Sectors by Planning Areas (citywide comparison)											
	1	% city	2	% city	3	% city	4	% city	5	% city	Total Sectors	
Very Low	45	2.2%	669	32.6%	510	24.9%	592	28.9%	232	11.3%	2051	100.0%
Low	79	3.9%	566	27.7%	764	37.4%	327	16.0%	310	15.2%	2045	100.0%
Average	113	5.5%	385	18.8%	889	43.5%	173	8.5%	491	24.0%	2046	100.0%
High	148	7.2%	245	12.0%	875	42.8%	114	5.6%	663	32.5%	2043	100.0%
Very High	188	9.2%	97	4.7%	676	33.0%	106	5.2%	976	47.7%	2048	100.0%
Total Sectors	**573**	**5.6%**	**1962**	**19.2%**	**3714**	**36.3%**	**1312**	**12.8%**	**2672**	**26.1%**	**10233**	**100.0%**

Table 6: Comparison of Sectors by Household Vulnerability Classes Citywide.

Map 6 and Table 7 and 8 show the category race & language of the SVI. It is possible to notice that in this category no AP has a disproportionate share of its Sectors in the high and very high vulnerability category. Nevertheless, AP2 does have a large proportion of its Sectors classified as low or very low vulnerability, with 73% of its Sectors in these classes, and concentrating 48% of all city's Sectors classified as having very low race & language vulnerability. AP4 also has a concentration of low and very low vulnerability Sectors, especially in its coastal area, with 51% of its Sectors in these categories, however, in a citywide comparison, it does not concentrate a large proportion of lower vulnerability Sectors. AP1 and AP3 have generally balanced rates of Sectors in each of the vulnerability categories, yet, AP3 concentrates 41% of all city's Sectors classified as low vulnerability. In AP2 and AP4 it is possible to notice that the Sectors with high or very high race & language vulnerability are located close to the 100m level curve. In the other APs, there are no visual patterns for the distribution of high and very high vulnerability Census Sectors. When analyzing the socioeconomic map and the race & language, it is possible to notice that there is a correlation between both, especially in AP2 and AP4, which reinforces the idea that in Brazil race and class are strongly correlated.

Table 7: Comparison of the Number of Sectors in Each Race & Language Vulnerability Classes by Planning Area

Race & Language	Sectors by Planning Areas									
	1		2		3		4		5	
Very Low	69	12.0%	978	49.8%	492	13.2%	394	30.0%	114	4.3%
Low	95	16.6%	459	23.4%	831	22.4%	272	20.7%	389	14.6%
Average	131	22.9%	272	13.9%	808	21.8%	209	15.9%	627	23.5%
High	146	25.5%	142	7.2%	777	20.9%	224	17.1%	757	28.3%
Very High	132	23.0%	111	5.7%	806	21.7%	213	16.2%	785	29.4%
Total Sectors	**573**	**100.0%**	**1962**	**100.0%**	**3714**	**100.0%**	**1312**	**100.0%**	**2672**	**100.0%**

Table 7: Comparison of Sectors by Race & Language Vulnerability Classes by AP.

Table 8: Comparison of the Number of Sectors in Each Race & Language Vulnerability Classes by Planning Area and Citywide												
Race & Language	Sectors by Planning Areas (citywide comparison)											
	1	% city	2	% city	3	% city	4	% city	5	% city	Total Sectors	
Very Low	69	3.4%	978	47.8%	492	24.0%	394	19.2%	114	5.6%	2047	100.0%
Low	95	4.6%	459	22.4%	831	40.6%	272	13.3%	389	19.0%	2046	100.0%
Average	131	6.4%	272	13.3%	808	39.5%	209	10.2%	627	30.6%	2046	100.0%
High	146	7.1%	142	6.9%	777	38.0%	224	10.9%	757	37.0%	2047	100.0%
Very High	132	6.4%	111	5.4%	806	39.4%	213	10.4%	785	38.3%	2047	100.0%
Total Sectors	**573**	**5.6%**	**1962**	**19.2%**	**3714**	**36.3%**	**1312**	**12.8%**	**2672**	**26.1%**	**10233**	**100.0%**

Table 8: Comparison of Sectors by Race and Language Vulnerability Classes Citywide.

Finally, Map 7 and Table 9 and 10 show the analysis of the built environment category. This category has the least disparity between APs, with all having a considerable proportion of its Sectors with high or very high built environment vulnerability. Even AP2, which has the lowest concentration of higher vulnerability Sectors still has a 25% of its Sectors classified as high and very high built environment vulnerability. In this category, AP1 and AP4 present the highest concentration of high and very high vulnerability, with 56% of AP1's Sectors and 52% of AP4's Sectors in these classes. Interestingly, AP3 concentrates 48% of all city Sectors with very low built environment vulnerability, even though in the other categories it leans towards the higher vulnerability classes. AP5, which has mostly Sectors with high and very high vulnerability in all other categories, does not stand out in this category. The distribution of high and very high built environment vulnerability does not show any spatial patterns.

Table 9: Comparison of the Number of Sectors in Each Built Environment Vulnerability Classes by Planning Area										
Built Environment	Planning Areas									
	1		2		3		4		5	
Very Low	27	4.7%	413	21.0%	966	26.0%	86	6.6%	592	22.2%
Low	60	10.5%	540	27.5%	618	16.6%	362	27.6%	453	17.0%
Average	165	28.8%	511	26.0%	763	20.5%	187	14.3%	399	14.9%
High	151	26.4%	240	12.2%	750	20.2%	307	23.4%	596	22.3%
Very High	170	29.7%	258	13.1%	617	16.6%	370	28.2%	632	23.7%
Total Sectors	**573**	**100.0%**	**1962**	**100.0%**	**3714**	**100.0%**	**1312**	**100.0%**	**2672**	**100.0%**

Table 9: Comparison of Sectors by Built Environment Vulnerability Classes by AP.

Table 10: Comparison of the Number of Sectors in Each Built Environment Vulnerability Classes by Planning Area and Citywide												
Built Environment	Planning Areas											
	1	% city	2	% city	3	% city	4	% city	5	% city	Total Sectors	
Very Low	27	1.3%	413	20.4%	966	47.7%	86	4.2%	592	29.2%	2025	100.0%
Low	60	2.9%	540	26.4%	618	30.2%	362	17.7%	453	22.2%	2044	100.0%
Average	165	8.1%	511	25.1%	763	37.5%	187	9.2%	399	19.6%	2033	100.0%
High	151	7.4%	240	11.7%	750	36.6%	307	15.0%	596	29.1%	2047	100.0%
Very High	170	8.2%	258	12.4%	617	29.6%	370	17.8%	632	30.3%	2084	100.0%
Total Sectors	**573**	**5.6%**	**1962**	**19.2%**	**3714**	**36.3%**	**1312**	**12.8%**	**2672**	**26.1%**	**10233**	**100.0%**

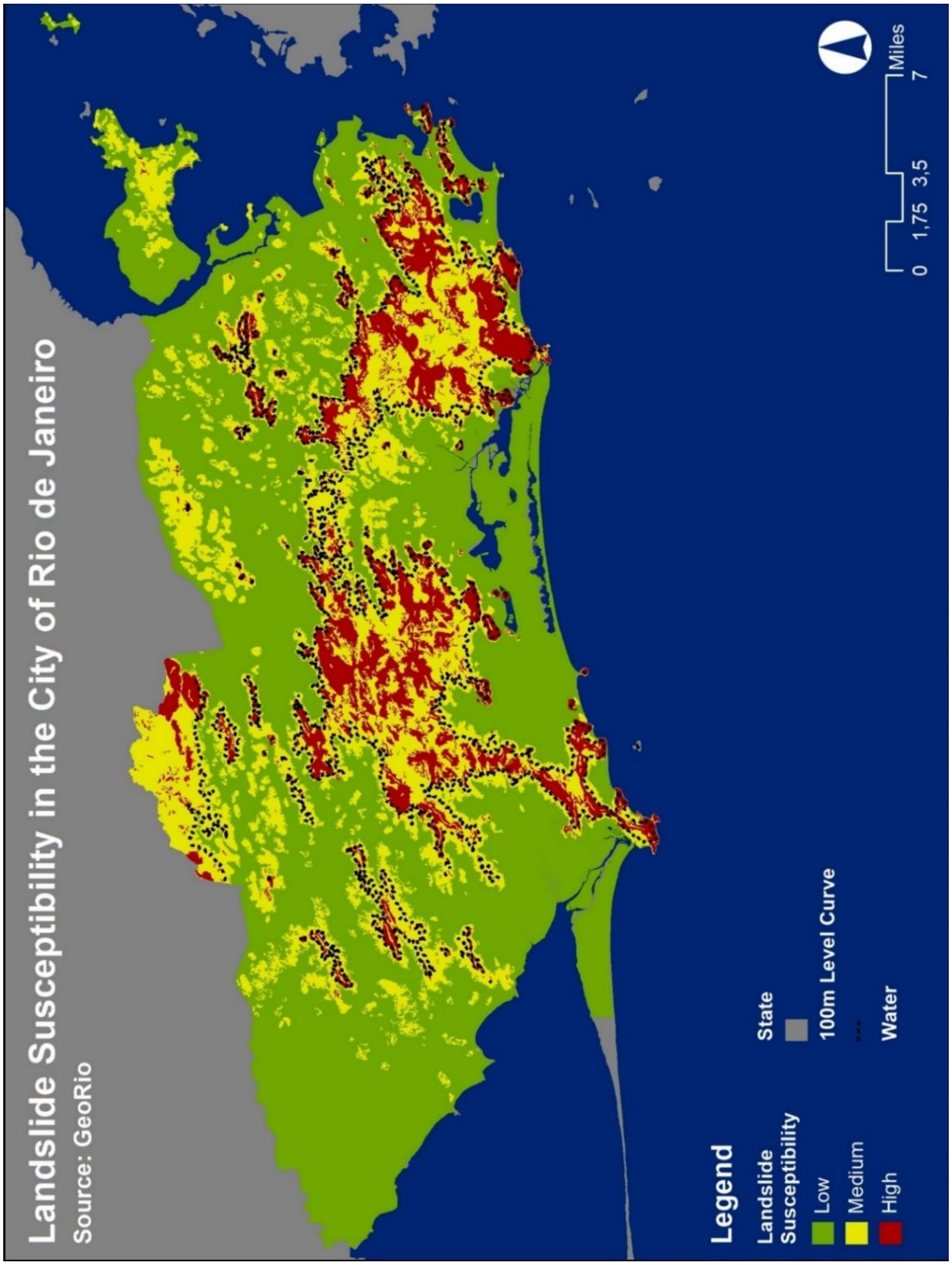
Table 10: Comparison of Sectors by Built Environment Vulnerability Classes Citywide.

The results for the built environment category may indicate a general lack of quality in the infrastructure of the city, which can be a result of years of disintegrated planning. However, it is also possible that the indicators chosen for this category were not adequate, and that different standards to evaluate the built environment in the city of Rio de Janeiro should be used. The indicators chosen for this category were based on the SoVI Brazil (Hummell et al., 2016), which had the goal of evaluating municipalities throughout the country, and although these indicators were significant in a country-wide evaluation, within municipalities they might not be representative. When analyzing the individual indicators for the built environment it is possible to notice not many Sectors had relevant numbers. For example, when looking into the indicator “households with open sewer”, only 920 out of 10,233 (around 9% of the total) Sectors had more than 10% of its households with open sewer. There is not a big difference in infrastructure quality and quantity between Census Sectors in Rio, which means that the gap between very low and very high built environment vulnerability is not significant. Another hypothesis is that the differences in the built environment quality might be only perceived at a smaller scale than Census Sectors.

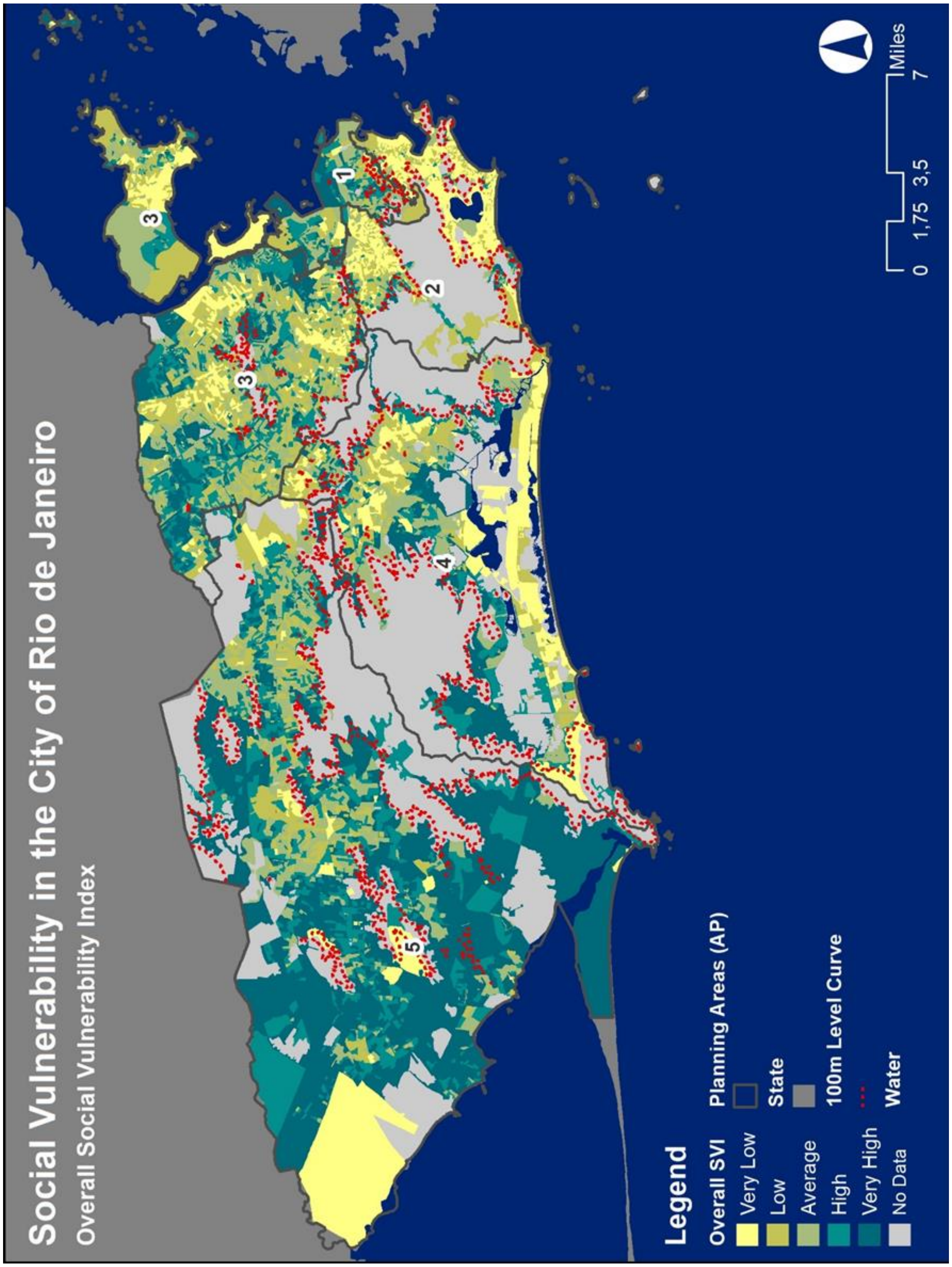
Besides the SVI analysis, it is possible to observe that the risk areas are not necessarily occupied by favelas, as Map 7 to Map 9 shows. This is noticeable because, as Barbosa & Walker (2020) show, in the past, the city has used exposure to landslides to justify favela clearance. In 2010, after a series of landslides the city launched a large program for the removal of houses in high-risk zones, however, the areas selected were mostly low-income areas, with upper- and middle-class areas excluded from the list even when they were in high-risk areas. The list also included three favelas that were not in high-risk zones (Barbosa&Walker, 2020). Although in AP1, AP2, and AP3 it is possible to notice some pattern of favelas locating in these areas, this is not observable in AP4 and AP5. The maps also show areas of medium and low vulnerability that are in risk areas in all APs. Additionally, there are many areas of high and very high vulnerability which are not favelas, and many favelas are located out of the high-risk areas.

The analysis of social vulnerability in the city shows that Sectors of high social vulnerability are found throughout the city. Nevertheless, AP2 stands out as a low vulnerability area, which aligns with what was discussed in Chapter 1. The area has historically differentiated itself from the rest of the city as a high-income and cosmopolitan area. It is the area where the city was founded and encompasses the most important touristic attractions of the city such as Copacabana beach, Sugarloaf Mountain, and Christ the Redeemer statue. The results show that AP2 has some of the most strong contrasts in the city, with most Sectors of low and very vulnerability, and few with very high vulnerability. Nevertheless, it is interesting to notice that the other areas of the city have less stark contrasts, having a mix of Sectors in all vulnerability levels.

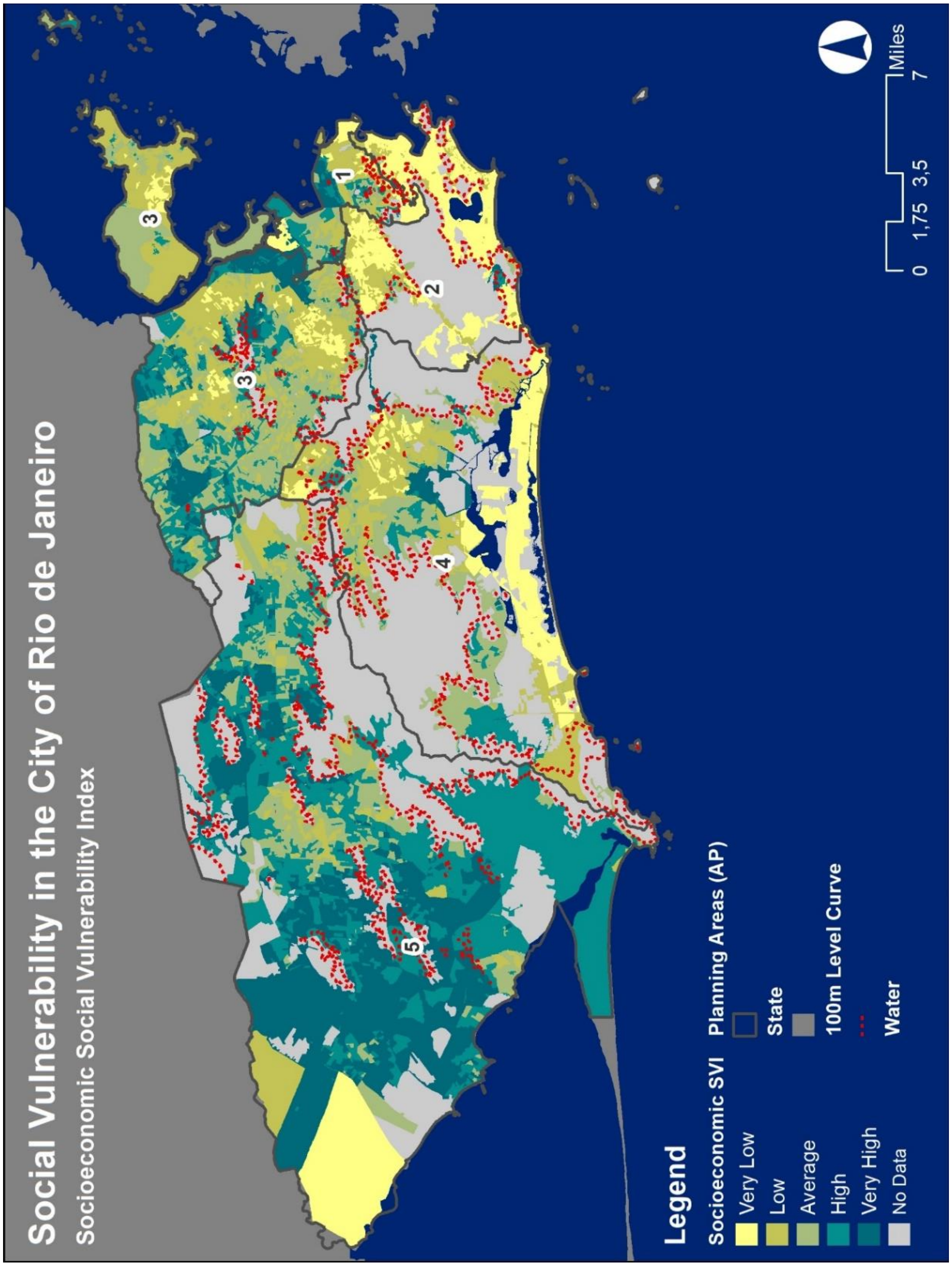
Maps



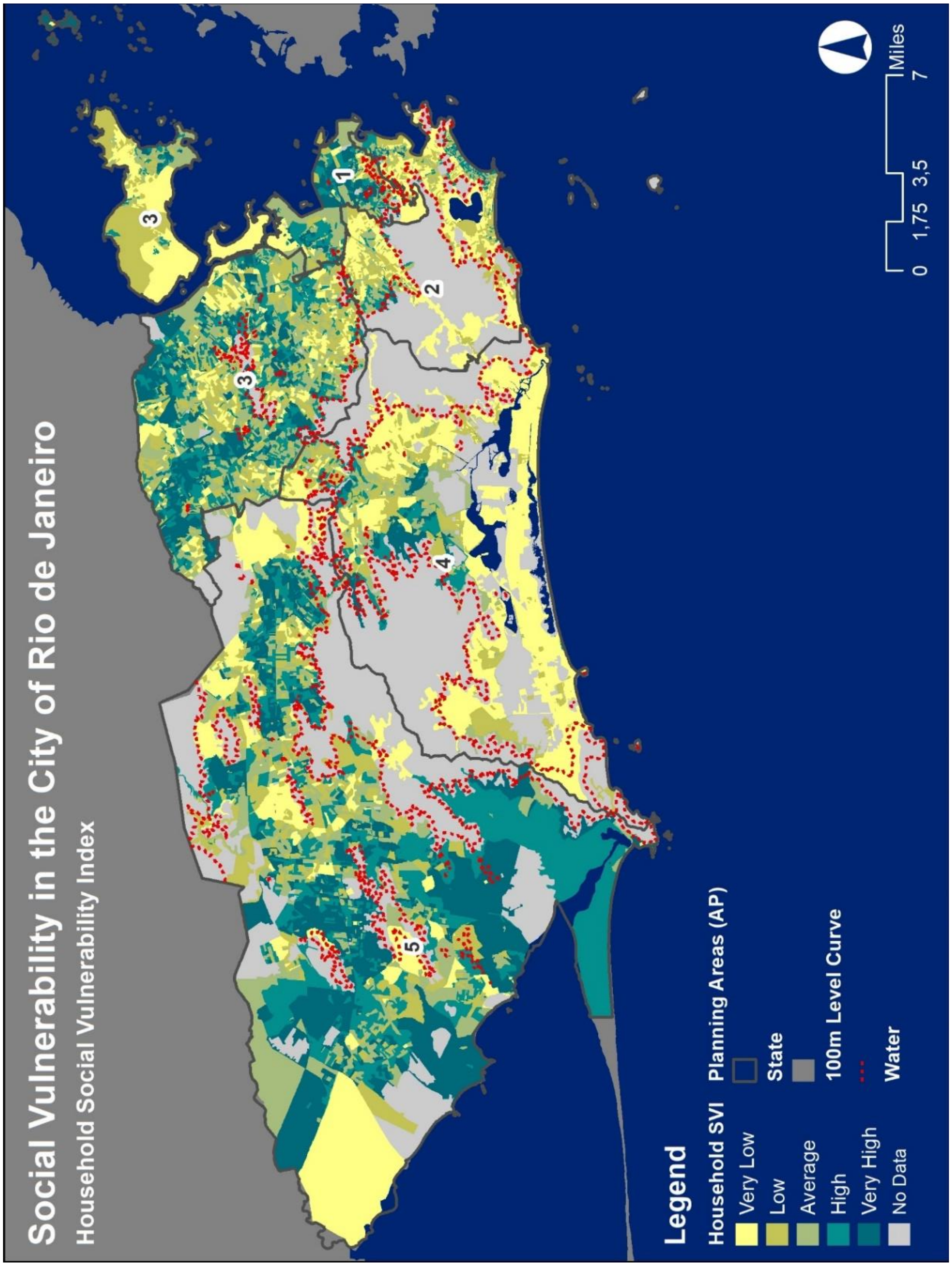
Map 1: Susceptibility to landslides in the city of Rio.



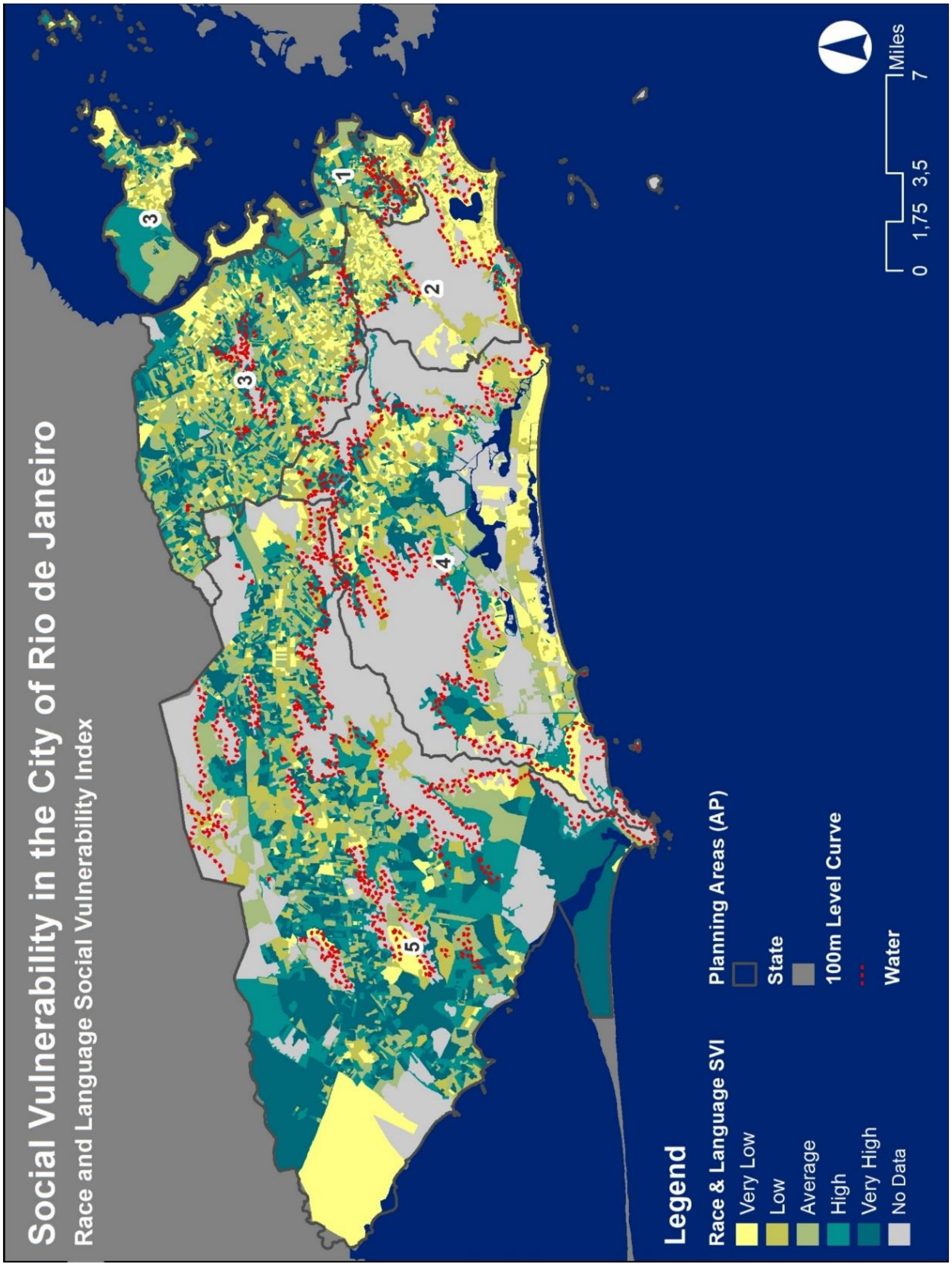
Map 2: Map of Overall SVI.



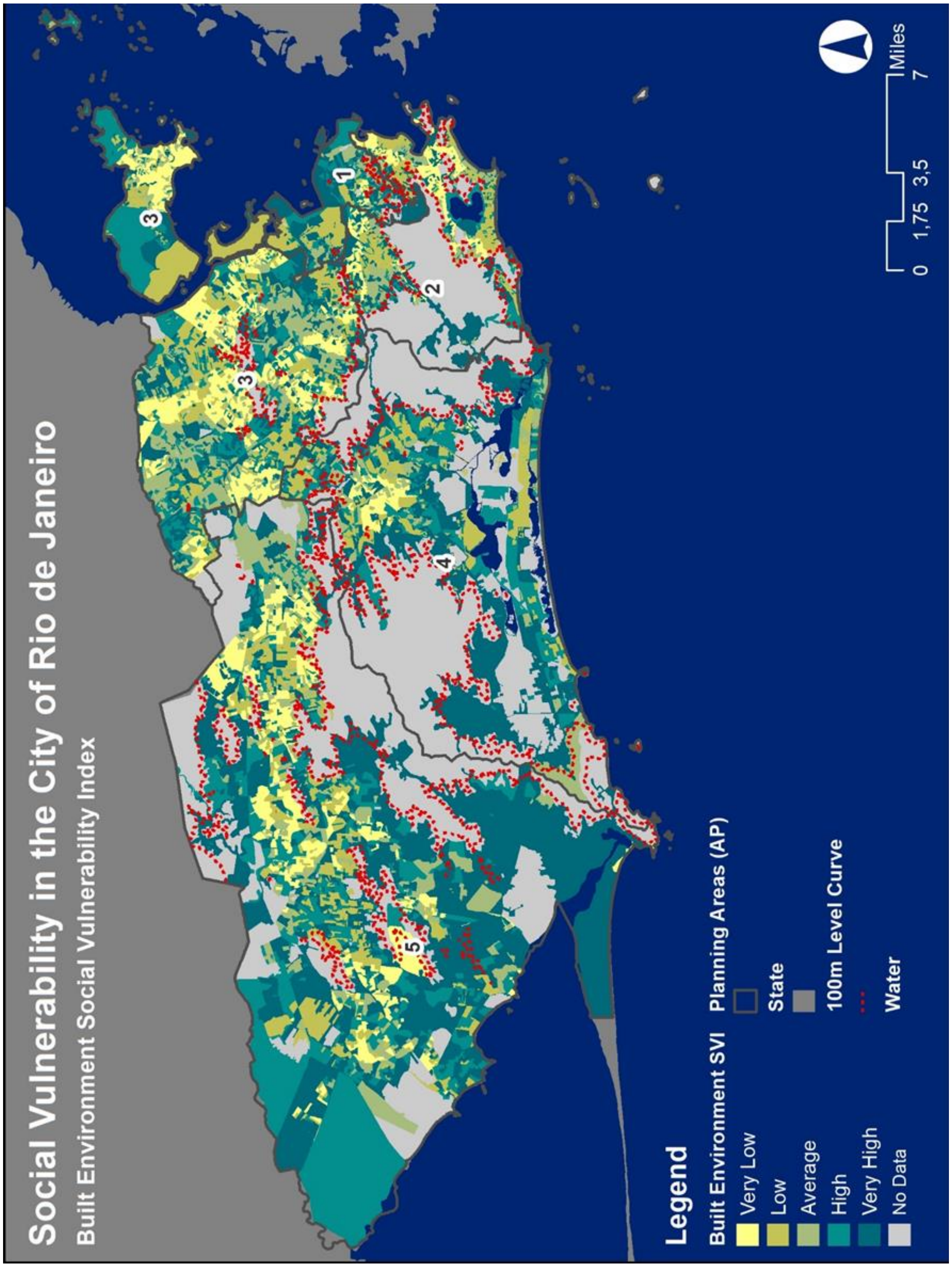
Map 3: Socioeconomic category of SVI.



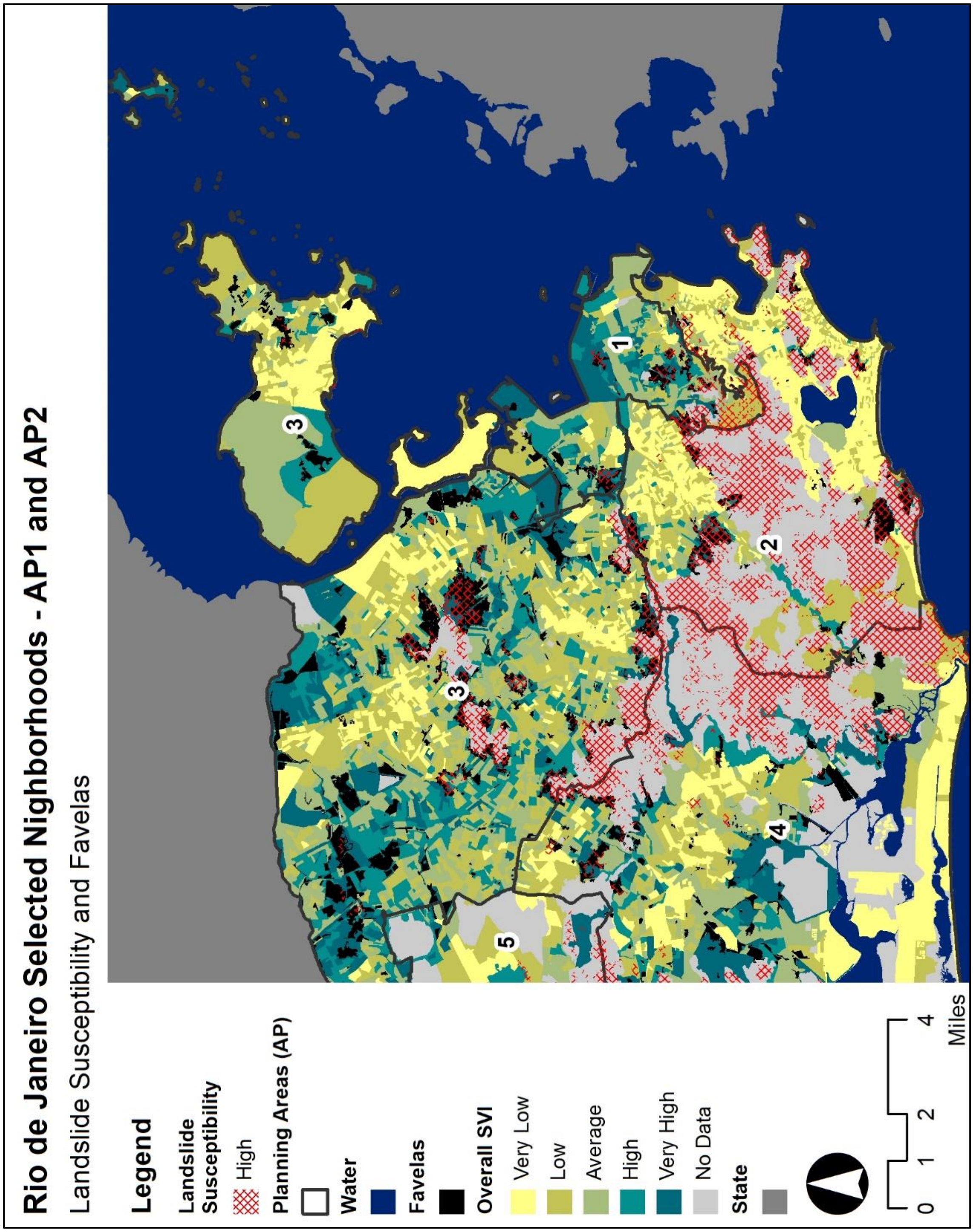
Map 4: Household category of SVI.



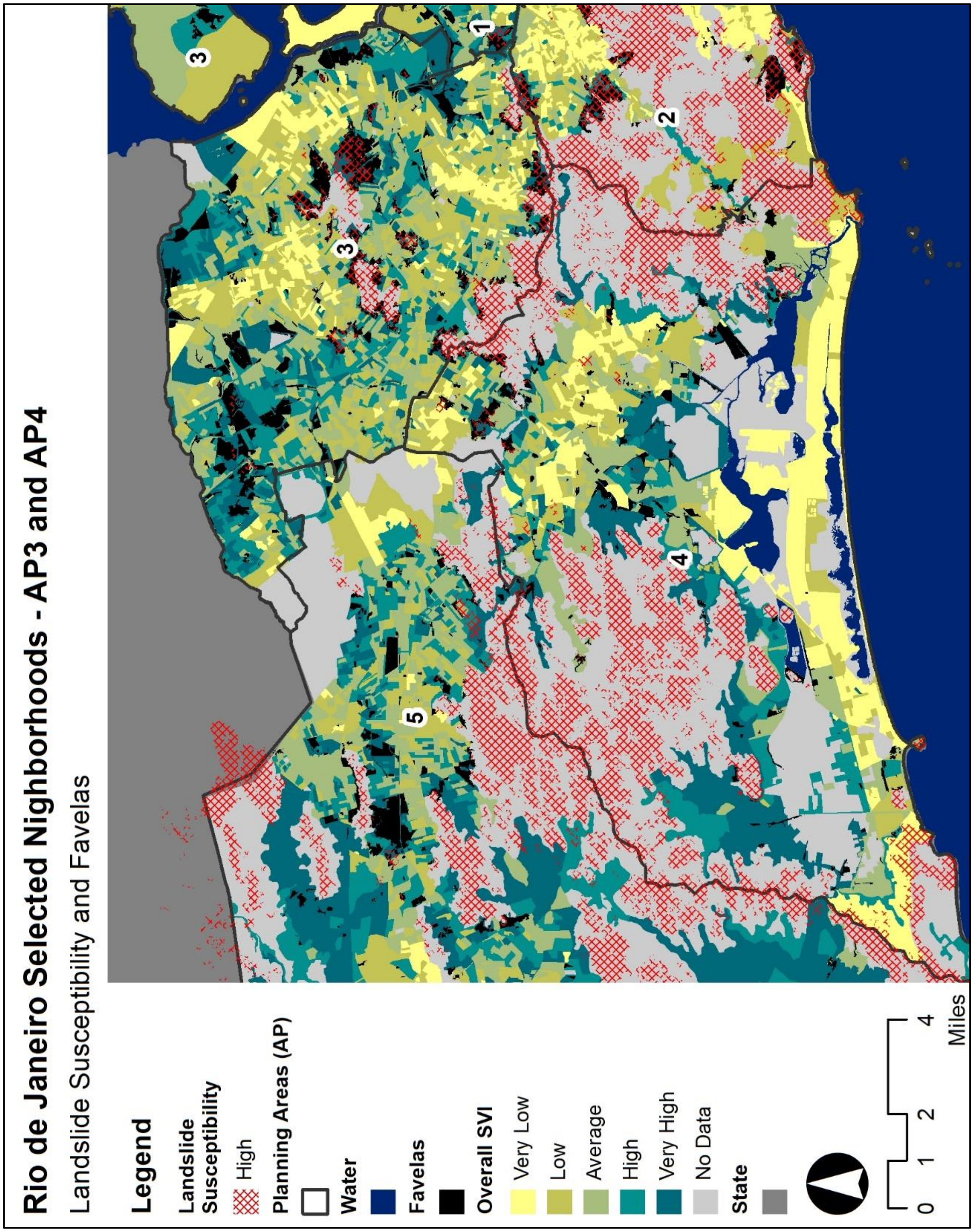
Map 5: Race and Language category of SVI.



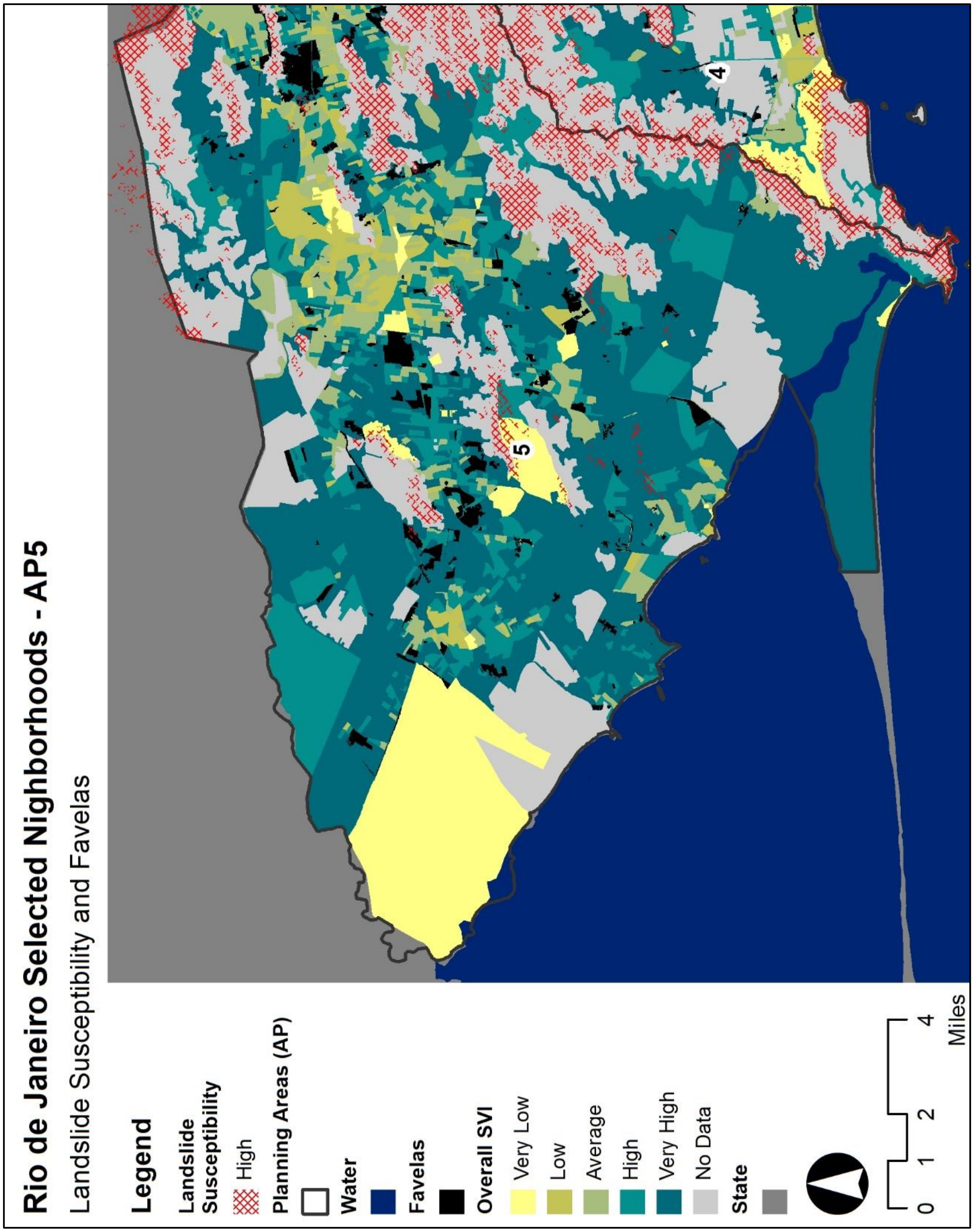
Map 6: Built Environment Category of SVI



Map 7: Comparison of location of favelas, areas with high susceptibility to landslides, and Overall SVI (AP1 and AP2).



Map 8: Comparison of location of favelas, areas with high susceptibility to landslides, and Overall SVI (AP3 and AP4).



Map 9: Comparison of location of favelas, areas with high susceptibility to landslides, and Overall SVI (AP5).

Correlation of SVI with Risk

The next step after mapping the SVI was to analyze any correlations between the SVI indicators and the risk of landslides. The first round of correlation calculations, where Sectors with 90% or more of their area in the medium and/or high-risk zones were analyzed, are shown in Table 11. When considering the 95% level of confidence no indicator showed a statistically strong correlation with risk, and some indicators did not have statistically significant correlations, this was the case for the unemployment rate, and some of the indicators in the built environment category, such as “households not serviced by the water utility company”, “households not serviced by the trash collecting company”, and “car ownership”. The index for built environment vulnerability also did not have statistically significant correlations, as observed in the mapping process.

From the indicators with statistically significant correlations, only a few had considerable relationships with risk. Some of the correlations were expected, such as the ones regarding race and socioeconomic status. From the four categories in the SVI, socioeconomic vulnerability and race & language vulnerability are the ones with the strongest correlation to risk. In the socioeconomic category, per capita income (PCI) shows the strongest correlation with risk, since the PCI indicator was calculated from highest to lowest, meaning low PCI was in the highest percentile, there is a positive correlation between risk and PCI, with R= 0.22. The indicator “population with less than a high-school diploma” also has a positive correlation with risk.

In the race & language category, the indicators for the Black population and Brown population have positive correlations with risk. This result is not surprising when considering the country's history of marginalizing these populations. These results reinforce again that race and class are inseparable in Brazil. A distinct correlation calculation was done comparing PCI and other indicators, showing a strong correlation between PCI and the rate of Black and Brown population, with R=0.79 between PCI and of Brown population, and R= 0.62 between PCI and Black population. The other indicator from the race & language category that showed a positive correlation with risk was the illiteracy rate, which together with the indicator for educational achievement indicates that lack of academic education may influence where people are located around the city. The illiteracy rate also had a strong positive correlation with PCI, with R=0.68. Additionally, illiteracy can hinder evacuation during emergencies since part of the Civil Defense's communication strategy is to send text messages to residents when there is a possibility of flooding or landslide (Rio, 2021).

When comparing risk with the household category it is interesting to notice that, although the overall index for this category does not show a significant relationship with risk, most of the individual indicators do. There is a positive correlation between "children below 18 years old living with only one parent" and risk. This indicator also showed a strong positive correlation with PCI, with R= 0.57, which might indicate that families without both parents have lower income, and consequently locate in risk areas. There was a surprising relationship between age and risk, the indicator "population below 14 years old" showed a positive correlation with risk, while "population above 60 years old" presented a negative correlation with risk. This result can be related to findings from Casa Fluminense (2020), that show a gap of more than twenty years in the life expectance between high- and low-income neighborhoods in the city of Rio, with areas of AP2 having a life expectance of 70 to 78 years, and areas of AP5 with a life expectance of 52 to 58 years (Casa Fluminense, 2020). This is also reinforced when calculating the correlation between PCI and age, where there was a strong positive correlation between PCI and “population below 14 years old”, with R= 0.79, and a strong negative correlation between PCI and “population above 60 years old”, with R= -0.75.

Finally, as discussed above, the indicators for the built environment proved to not have a strong relationship with risk, which is also surprising. Based on the literature review it was expected that landslide-prone areas were occupied irregularly, resulting in a low-quality built environment, however, this was not proven when mapping SVI. The only two indicators in this category that showed some relationship with risk were “rate of households with open sewer” and “rate of inadequate housing”, nevertheless, both were negative correlations. Although not included in the index, a correlation calculation was done between risk and subnormal agglomerates, which is how the Census classifies favelas, but again no significant relationship was found. These results may indicate that the city has done a good job in not allowing precarious occupations in risk areas.

Table 11: Pearson's correlation with Sectors in Medium and/or High Risk Zones		
Indicators vs. Risk	**R**	**p-value (2-tailed)**
People Living Below Poverty	**0.06**	0.0262
Unemployed	-0.01	0.6243
Per Capita Income	**0.22**	0.0000
People with Less Than a High School Diploma	**0.11**	0.0000
Socioeconomic Index	**0.12**	0.0000
Age 60 or Older	**-0.24**	0.0000
Age 14 or Younger	**0.18**	0.0000
Older Than Age of 5 With a Disability	**-0.06**	0.0125
Children Below 18y.o. Living With Only One Parent	**0.17**	0.0000
Household Composition and Disability Index	**0.05**	0.0418
Black	**0.14**	0.0000
Asian	**0.06**	0.0279
Brown	**0.15**	0.0000
Indigenous	**-0.05**	0.0342
Illiterate Above 15 y.o.	**0.20**	0.0000
Race and Language Index	**0.16**	0.0000
Inadequate Housing	**-0.11**	0.0000
No Water Utility	0.02	0.3709
Open Sewer	**-0.10**	0.0000
No Trash Utility	0.04	0.1266
No Car	0.02	0.5466
Wall quality	**0.08**	0.0016
Group Quarters	**-0.09**	0.0005
Built Envrionment Index	0.02	0.3444
Overall Social Vulnerability Index	**0.13**	0.0000
Correlations in bold are significant at the 5% level (2-tailed).		

Table 11: Pearson's correlation results for comparison between Sectors in medium and/or high-risk zones and all indicators.

The second round of correlations calculations was done considering only high-risk areas, and it is shown in Table 12. When comparing indicators with high-risk zones only a few indicators had statistically significant correlations when considering a 95% level of confidence. None of the index's four categories presented significant correlations. The only indicators that showed some relationship with risk were, unemployment rate, age, and illiteracy rate. The same trend is observed when comparing medium and/or high risk to age and when comparing just high-risk to age, which is that younger populations have a positive correlation with high-risk and older populations have a negative correlation with high-risk, which again might be related to the difference in life expectance between income groups. The unemployment rate showed a negative correlation with high-risk; it is not clear the reason behind this result, however, it reinforces the other results which indicated that locating in high-risk areas might not be directly related to socioeconomic status. Finally, the illiteracy rate has a positive correlation with high risk, which might indicate that this population is one of the most vulnerable in the city. Although the overall illiteracy rate for the city is not high, it does relate to PCI as mentioned previously.

Table 12: Pearson's correlation with Sectors in High Risk Zones		
Indicators vs. High Risk	**R**	**p-value (2-tailed)**
People Living Below Poverty	0.08	0.3155
Unemployed	**-0.17**	**0.0255**
Per Capita Income	0.03	0.7321
People with Less Than a High School Diploma	-0.03	0.6424
Socioeconomic Index	-0.05	0.5285
Age 60 or Older	**-0.15**	**0.0455**
Age 14 or Younger	**0.19**	**0.0127**
Older Than Age of 5 With a Disability	-0.09	0.2213
Children Below 18y.o. Living With Only One Parent	0.11	0.1335
Household Composition and Disability Index	0.03	0.6464
Black	0.10	0.1651
Asian	-0.10	0.1866
Brown	-0.01	0.9394
Indigenous	-0.07	0.3774
Illiterate Above 15 y.o.	**0.16**	**0.0332**
Race and Language Index	0.02	0.8133
Inadequate Housing	0.09	0.2228
No Water Utility	0.04	0.5822
Open Sewer	-0.06	0.4453
No Trash Utility	0.00	0.9472
No Car	0.10	0.1877
Wall quality	0.03	0.7086
Group Quarters	0.06	0.3905
Built Envrionment Index	0.05	0.5403
Overall Social Vulnerability Index	0.01	0.8662
Correlations in bold are significant at the 5% level (2-tailed).		

Table 12: Pearson's correlation results for comparison between Sectors in high-risk zones and all indicators.

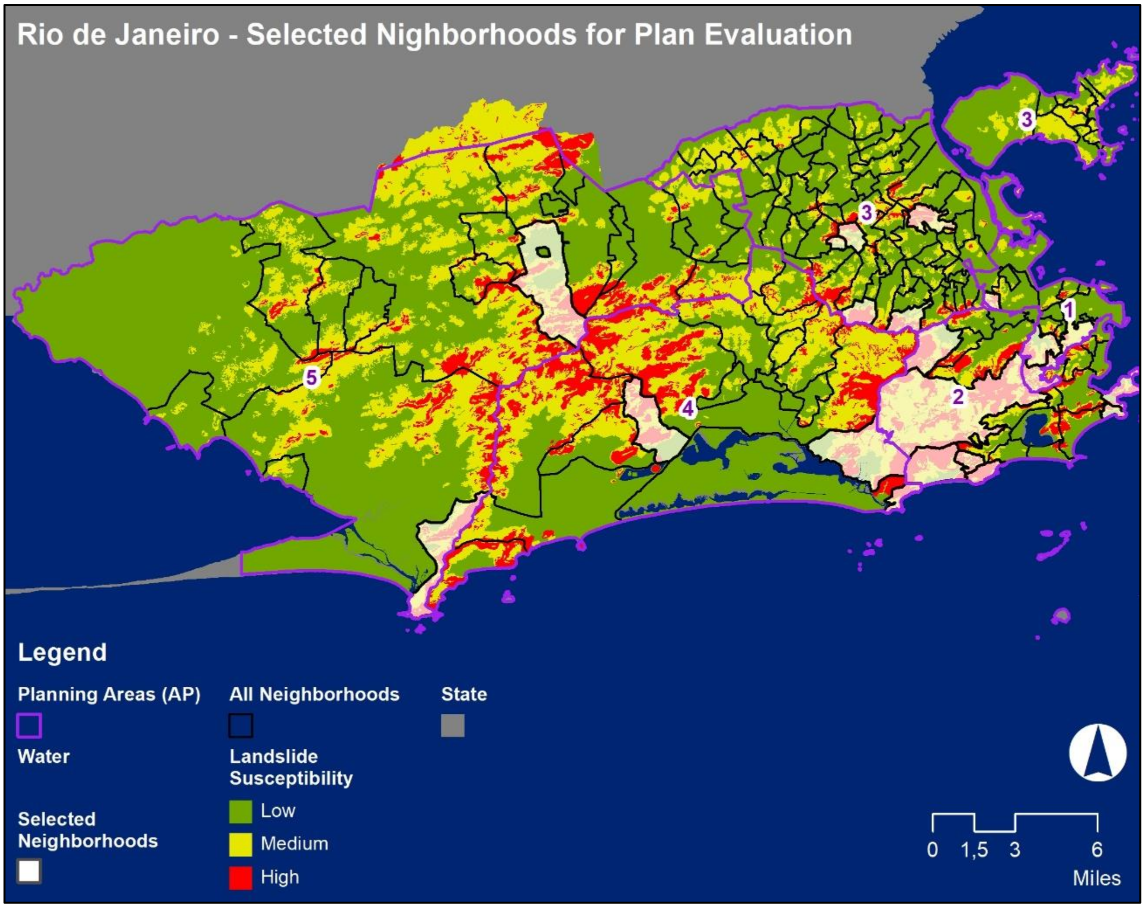
Although the overall results from the correlations between risk and SVI were not very strong planners and policymakers should still take into account social vulnerability when developing policies and plans. If we consider that equitable policies should be thought out in a way that not only does not harm the most vulnerable but also improves their conditions, SVI could be used beyond risk assessment. It should be considered when developing any policy, making sure it does not have disparate impacts on any population. By including different indicators the SVI has the potential of showing vulnerabilities policymakers might not be aware of or were not paying attention to. Additionally, SVI can help identify areas of the city that need further investment, for example, in areas with high household vulnerability the city can offer more services related to family support. When considering landslide risk, these areas can also receive specific training for evacuating with young children, or have more shelters, so elders and people with disabilities can access them more easily.

The correlation calculations also reinforce the importance of race and income in determining where people are located around the city. Although there was no correlation between favelas and risk, there were correlations between risk and low-income populations, and risk and race. Although not a statistically strong correlation, this result can have the effect of reinforcing stigmatization of these groups, causing planners and policymakers to only focus on these groups when discussing removing people from risk areas, reenacting racist and inequitable policies, such as the case presented by Barbosa & Walker (2020), where favelas which were not at risk were selected for removal. People making decisions must be aware of these biases, and not focus on relocation policies only in low-income areas. Dealing with disaster risk is a complicated matter, especially when considering social vulnerability. Mitigation strategies must be put in place to protect against loss of life and property, nevertheless, disaster mitigation should not be used as an excuse for inequitable policies and unnecessary displacement.

PLAN NETWORK EVALUATION

Selected Neighborhoods

After mapping and analyzing social vulnerability and risk around the city, it was necessary to evaluate the plans that affect development. Twenty neighborhoods with the most risk were selected, as it is shown in Map10, and the mappable policies for each were scored. The selected neighborhoods are:



Map 10: Selected neighborhoods for evaluation of plan network.

- Água Santa

Located in AP3, Água Santa has 55% of its total area in the zone of very high landslide susceptibility. It had its first developments in 1917, and in 1997 the highway Linha Amarela, which connects the regions North and West of the city, was inaugurated, with a toll charging station as a major infrastructure point in the neighborhood. Água Santa has an area of 242.6 acres, with 2,498 households. It has a population of 8,756 people, and 45% identify as Black or Pardo. The neighborhood has 29% of its area developed, being mostly residential uses, although not exclusively. Most of its households are single-family, however, about a third are multi-family units. Água Santa has four communities classified as favelas, which house 17% of the neighborhood's population. (IPP, n.d.). Part of its area is classified as a conservation area in the plan for the Atlantic Forest conservation, and the rest is classified as sustainable use, meaning development must be aligned with environmental protection strategies (Rio, 2015; Município do Rio de Janeiro, 2011). The neighborhood has average levels of overall social vulnerability and average levels of vulnerability in the four SVI categories.

Figure 8: Satellite image of Água Santa neighborhood (Google, 2021)

- Alto da Boa Vista

The neighborhood is located in AP2 and it has 39% of its total area in the zone of very high landslide susceptibility. It has most of its area occupied by an Atlantic Rainforest reserve, which is considered one of the biggest urban parks in the world. Alto da Boa Vista has a total area of 3,149.6 acres, and a total population of 9,343 residents, of which 37% identify as Black or Pardo. Only 6% of its area is developed, mainly with single-family residential uses, with a total of 2,972 households. There are ten communities classified as favelas, housing 43% of the neighborhood's population (IPP, n.d.). Most of the neighborhood's area is classified as a conservation area, and the rest is classified as sustainable use (Rio, 2015). In the 1980s and 1990s, the neighborhood experienced four historic landslides which, although did not cause loss of life, did cause loss of property and disruptions in the city's infrastructure (D'Orsi et al, 2016). Regarding SVI, the neighborhood has average levels of overall vulnerability, mostly because of the very high vulnerability in the built environment category since the other three categories show low levels of vulnerability.

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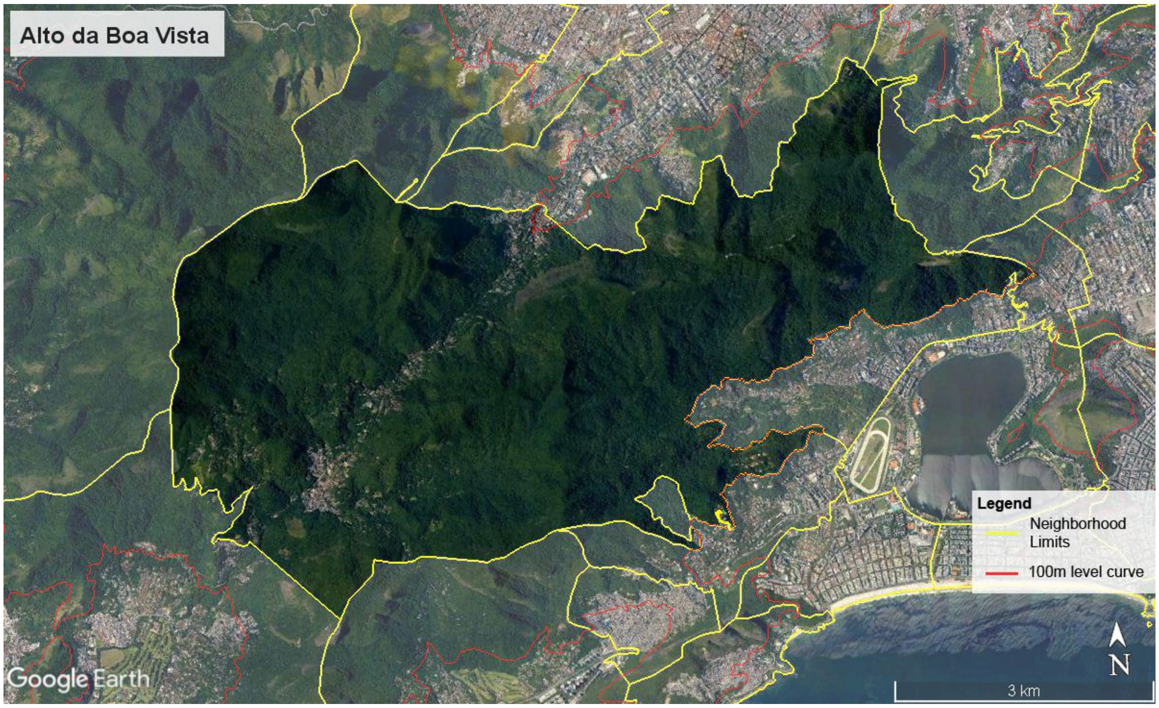


Figure 9: Satellite image of Alto da Boa Vista neighborhood (Google, 2021).

- Barra de Guaratiba

Located in AP5, the neighborhood has 43% of its total area in the zone of very high landslide susceptibility. Most of Barra de Guaratiba is environmentally protected, with areas of archeologic importance. The neighborhood has an area of 944.2 acres, it houses 3,577 people in a total of 1,172 households, and 60% of the population identify as Black or Pardo. Only 17% of its area is developed, with mainly single-family residential uses. There is only one community in the neighborhood classified as a favela, which houses 167 people (IPP, n.d.). The neighborhood area is equally divided between conservation areas and sustainable use areas (Rio, 2015). Its Sectors present mostly high and very high levels of overall social vulnerability, showing medium to high levels of vulnerability in each of four SVI categories.

Figure 10: Satellite image of Barra de Guaratiba neighborhood (Google, 2021).

- Camorim

Camorim is located in AP4, and 42% of its total area is in the zone of very high landslide susceptibility. It encompasses a big area of environmental protection, with trails and waterfalls, as well as one of the biggest convention centers in Latin America. The neighborhood has a total area of 886 acres, 1,970 people, and 655 households, with 51% of the residents identifying as Black or Pardo. The neighborhood is only 19% developed, it has mostly residential uses and a balanced mix of single-family and multi-family buildings. There are three communities classified as favelas, with a total of 221 residents (IPP, n.d.). Most of the neighborhood is classified as a conservation area, and there are no sustainable use areas (Rio, 2015). The area has a mix of Sectors of very low and very high overall social vulnerability, for the SVI categories of socioeconomic and household vulnerability the neighborhood shows low levels of vulnerability, however, for the SVI categories of the built environment, and race and language, it has mostly high levels of vulnerability.

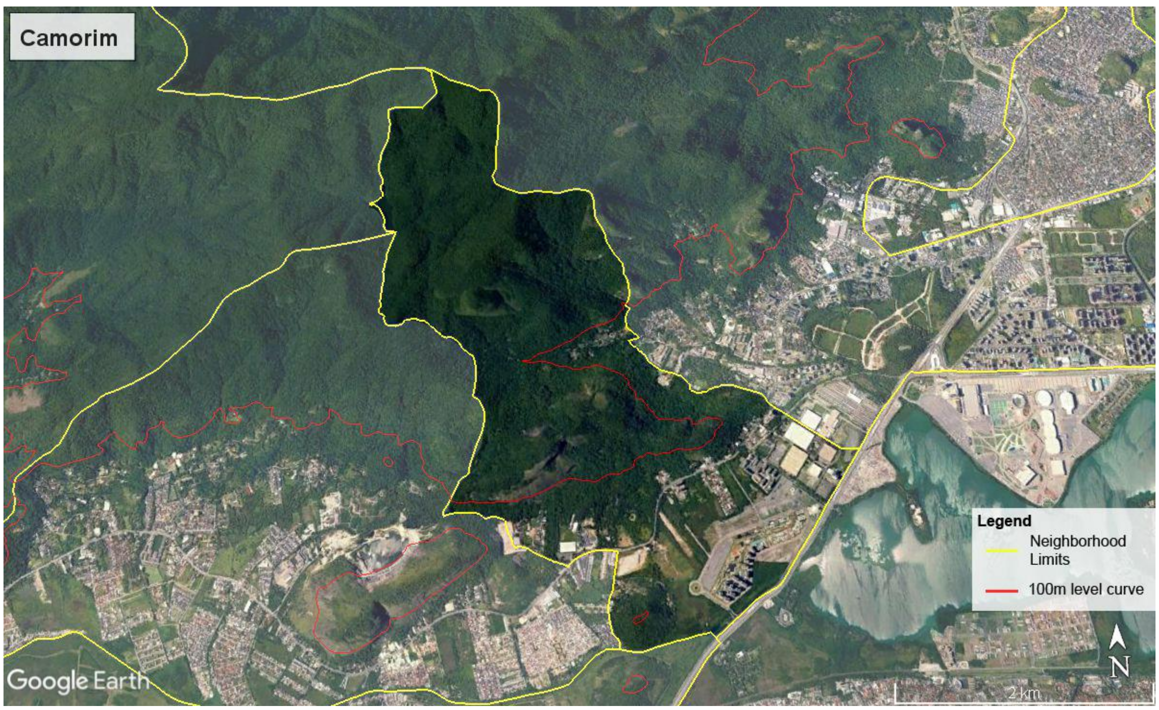


Figure 11: Satellite image of Camorim neighborhood (Google, 2021).

- Cavalcanti

This neighborhood is located on AP3 and has 31% of its total area in the zone of very high landslide susceptibility. It is crossed by an old railway, first built in 1892, which is currently used as a transit line. Cavalcanti has a total area of 192.4 acres, with 68% developed, and mainly single-family residential uses. It has a total population of 16,141 residents, and 5,265 households, with 55% of the residents identifying as Black or Pardo. There are five communities classified as favelas in the area, housing 14% of the total population (IPP, n.d.). The neighborhood does not have any environmentally protected areas, only areas marked for sustainable use (Rio, 2015). Cavalcanti has medium to high levels of overall social vulnerability, in the SVI categories for socioeconomic and household vulnerability, it shows mostly medium to low levels of vulnerability, with the SVI categories of built environment, and race and language showing higher levels of vulnerability.

Figure 12: Satellite image of Cavalcanti neighborhood (Google, 2021).

- Complexo do Alemão

  The Complexo do Alemão neighborhood is located on AP3 and has 43% of its total area in the zone of very high landslide susceptibility. It had mostly low-density development until the 1950s when more intense development happened. Most of the neighborhood is classified as a favela, it has a total area of 296.1 acres, with 21,035 households, and 69,143 residents, of which 66% identify as Black or Pardo, and 84.3% live in favelas. The neighborhood is 89% developed, with a mix of residential and other uses, and mostly single-family developments (IPP, n.d.). The entire neighborhood is classified as sustainable use in the plan for the Atlantic Forest conservation (Rio, 2015). The neighborhood experienced a major landslide in 2001, where many houses were lost and four people died (D'Orsi et al., 2016). Regarding social vulnerability, the neighborhood presents high to very high overall vulnerability, showing mostly high vulnerability in each of the four SVI categories.

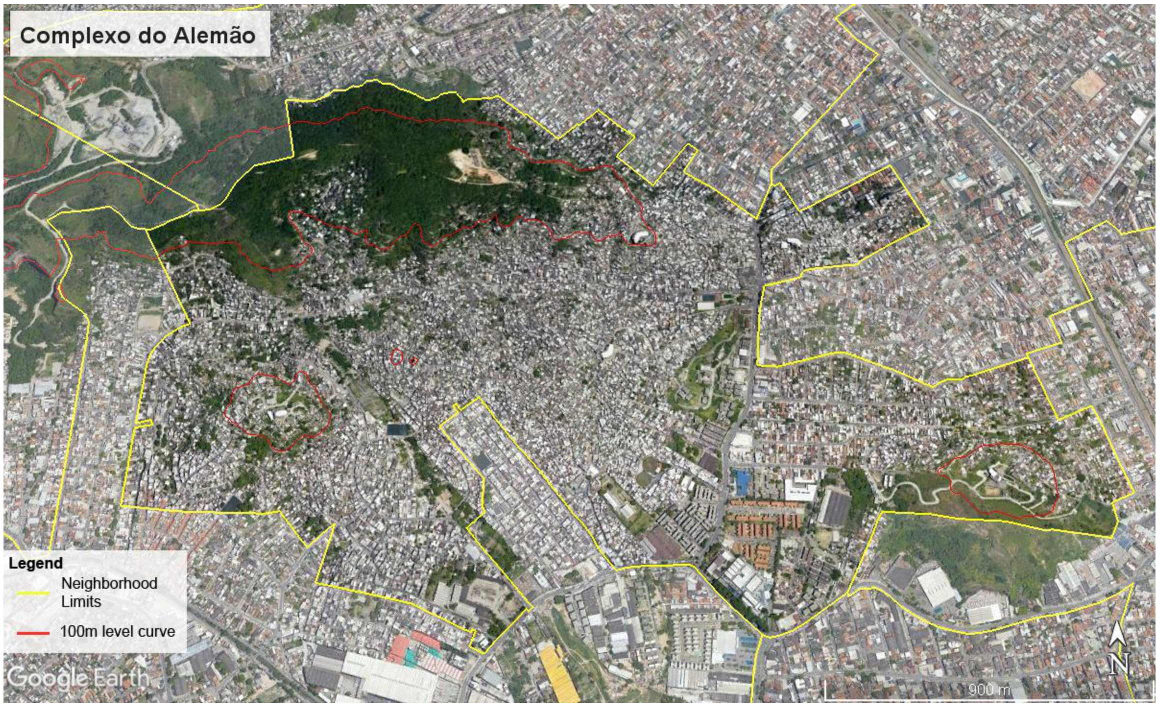


Figure 13: Satellite image of Complexo do Alemão neighborhood (Google, 2021).

- Engenheiro Leal

Located on AP3, Engenheiro Leal has 30% of its total area in the zone of very high landslide susceptibility. It is a small neighborhood crossed by the same rail line that passes through the Cavalcanti neighborhood. With a total area of 70.8 acres and 1,885 households, it has 6,113 residents, of which 62% identifies as Black or Pardo. It is 68% developed, with a mix of residential and other uses, with mainly single-family houses. There are three communities in the neighborhood classified as favelas, housing 23% of the total population (IPP, n.d.). It is entirely classified as an area of sustainable use (Rio, 2015). Engenheiro Leal shows medium to very high levels of overall vulnerability, with medium to high vulnerability in each of the four SVI categories.

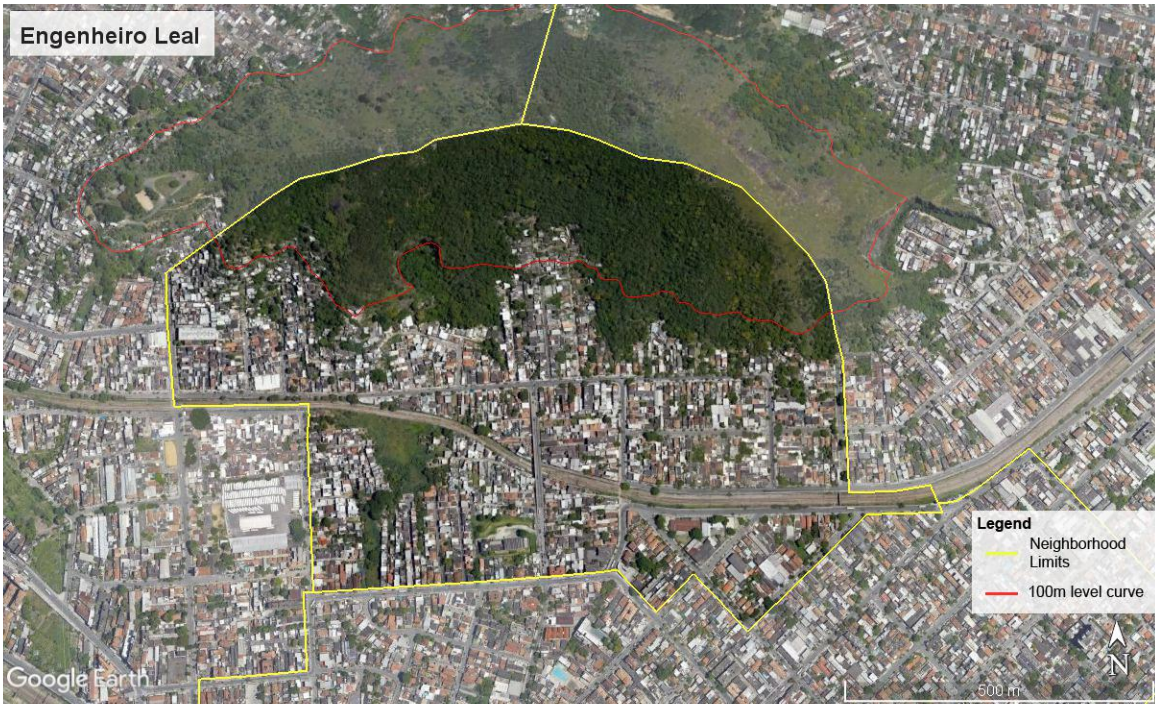


Figure 14: Satellite image of Engenheiro Leal neighborhood (Google, 2021).

- Grajaú

Located in AP2, it has 47% of its total area in the zone of very high landslide susceptibility. The neighborhood encompasses a big state park and it was first occupied in the 1920s. Grajaú has a total area of 573.9 acres and it is 31% developed, with mainly residential use and multi-family buildings. There is a total of 38,671 residents, occupying 14,203 households, and 24% identifying as Black or Pardo. There are three communities in the area classified as favelas, which house 14% of the neighborhood's population (IPP, n.d.). Almost half of the neighborhood is classified as a conservation area (Rio, 2015). It presents mixed levels of overall social vulnerability, with some Sectors with very low and low vulnerability and others with high vulnerability, and the same mix is seen in the race and language category. For the built environment category it shows mostly high vulnerability levels, the household category presents mostly medium levels of vulnerability, and the socioeconomic category shows low levels of vulnerability.

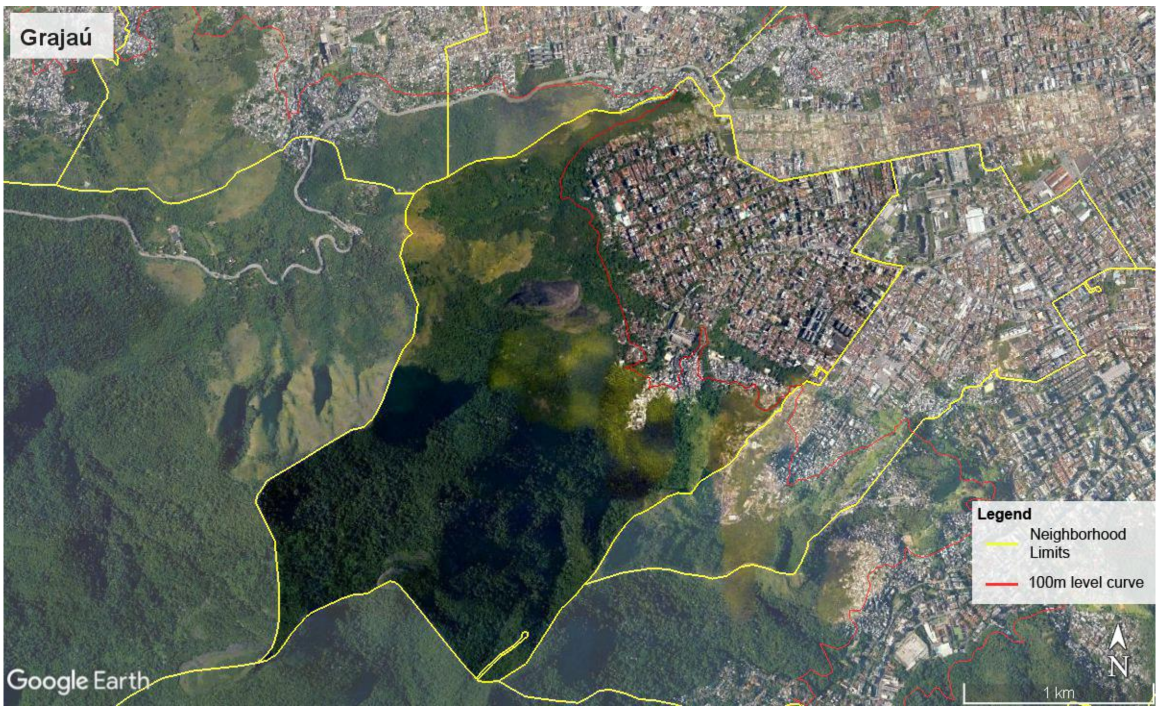


Figure 15: Satellite image of Grajaú neighborhood (Google, 2021).

- Itanhangá

The neighborhood is located in AP4 and it has 32% of its total area in the zone of very high landslide susceptibility. It was an extensive golf course at the beginning of the 20th century, and subdivisions were first developed in the 1950s. It has a total area of 1,319.8 acres, and it is 32% developed. It has a total of 38,415 residents, living in 12,782 households, and 48% of the population identify as Black or Pardo. It has a mix of residential and other uses, with a mix of single-family and multi-family developments (IPP, n.d.). The neighborhood has areas classified as conservation areas as well as sustainable use areas, although it is not the majority (Rio, 2015). It suffered two major landslides in 1996, which caused major damage to infrastructure, 70 destructed houses, and a total of 21 deaths (D'Orsi, 2016). Itanhangá presents mostly medium to very high overall social vulnerability, with very high built environment vulnerability, medium levels of socioeconomic and race and language vulnerability, and very low levels of household vulnerability.

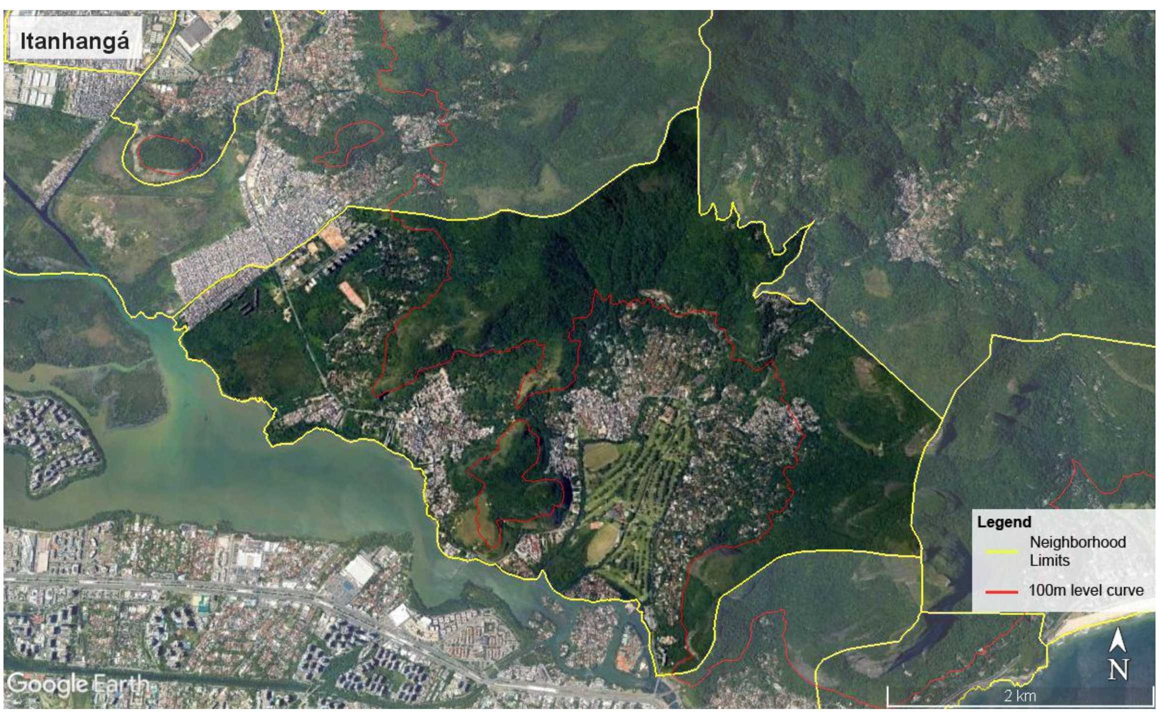


Figure 16: Satellite image of Itanhangá neighborhood

- Joá

The Joá neighborhood is located on AP4 and it has 65% of its total area in the zone of very high landslide susceptibility. With mostly gated communities, it has a total area of 169 acres and is 27% developed. There is a total of 250 households, and 818 residents, of which 13% identify as Black and Pardo. There are no favelas in the area (IPP, n.d.). The neighborhood is partially classified as a conservation area (Rio, 2015). It presents very low levels of vulnerability in the overall SVI index as well as in each of the individual categories, except for the built environment category, where it shows high levels of vulnerability.

Figure 17: Satellite image of Joá neighborhood (Google, 2021).

- Leme

The Leme neighborhood is located in AP2 and has 28% of its total area in the zone of very high landslide susceptibility. Its first developments date back from 1892, with more intense development in the 1930s. It is densely occupied, it has a total area of 97.7 acres with 6,229 households, and 14,799 residents, of which 27% identify as Black or Pardo. The neighborhood is 38% developed, and has a mix of residential and other uses, with mostly multi-family buildings. There are two communities in the area classified as favelas, making up 25% of the population (IPP, n.d.). The neighborhood is partially classified as sustainable use in the plan for the Atlantic Forest conservation (Rio, 2015). It is mostly a neighborhood of contrast, with most Sectors showing very low overall vulnerability and a few with very high vulnerability. For the built environment, household, and race and language categories the same contrast is seen. However, the socioeconomic category shows mostly low to very low levels of vulnerability, without any Sectors of high vulnerability.

Figure 18: Satellite image of Leme neighborhood (Google, 2021).

- Lins de Vasconcelos

Located at AP3, Lins de Vasconcelos has 39% of its total area in the zone of very high landslide susceptibility. It was occupied in the late 19th century and had a military base during World War II. The neighborhood has an area of 266.9 acres, 12,262 households, and 37,487 residents, of which 53% identifies as Black or Pardo. 63% of its area is developed, with mixed uses, and a balanced mix of single-family and multi-family buildings. There are eleven communities classified as favelas, housing 35% of the total population (IPP, n.d.). The neighborhood has small areas classified as conservation areas and sustainable use areas (Rio, 2015). It has a balanced mix of Sectors with lower and higher vulnerability in all SVI categories.

Figure 19: Satellite image of Lins de Vasconcelos neighborhood (Google, 2021).

- Mangueira

Mangueira is a neighborhood located in AP1, it has 32% of its total area in the zone of very high landslide susceptibility. It is historically black, and in the 1920s and 1930s it became a hub for Samba music, and still today it has an important Samba group. It has an area of 79.8 acres, with 5,080 households, and 17,835 residents, of which 74% identify as Black or Pardo. The area is 82% developed, with mostly single-family residential uses. There are three communities in the area classified as favelas, representing 30% of the total population (IPP, n.d.). There are no areas of environmental protection in the neighborhood (Rio, 2015). Regarding social vulnerability, the neighborhood presents high to very high levels of vulnerability in the overall index, as well as in each of the four SVI categories.

Figure 20: Satellite image of Mangueira neighborhood (Google, 2021).

- Rio Comprido

Located in AP1, Rio Comprido has 29% of its total area in the zone of very high landslide susceptibility. Its occupation dates back to the beginning of the 20th century, and in 1987 the inauguration of the Rebouças road tunnel made the neighborhood the main access between the North and South region of the city. It has a total area of 334.3 acres, of which 62% is developed, with mixed-use and a balance between single-family and multi-family development. There is a total of 14,357 households, and 43,764 residents, of which 46% identify as Black or Pardo. There are fifteen communities classified as favelas in the neighborhood, making up 2% of the total population (IPP, n.d.). There are no areas of environmental protection in the neighborhood (Rio, 2015). Rio Comprido suffered a major landslide in 2010, which caused 30 deaths, and major loss of property (D'Orsi, 2016). The neighborhood has medium to high levels of overall social vulnerability. In the household and built environment categories it shows mostly high levels of vulnerability, for the race and language category, it presents a mix of Sectors with very low and very high vulnerability, and for the socioeconomic category, it presents medium and low levels of vulnerability.

Figure 21: Satellite image of Rio Comprido neighborhood (Google, 2021).

- Rocinha

  The neighborhood is located in AP2 and has 62% of its total area in the zone of very high landslide susceptibility. Its first developments started in the 1930s, and it intensified in the 1950s with the immigration of people coming from the Northeast region of the country. The entire neighborhood is considered a favela, with a total area of 143.7 acres it is 59% developed, with mainly residential single-family development. There are a total of 23,399 households, and 69,356 residents, of which 56% identify as Black or Pardo (IPP, n.d.). Part of the neighborhood is classified as sustainable use in the plan for the Atlantic Forest conservation (Rio, 2015). Between 1988 and 2010 the neighborhood suffered four major landslides that caused loss of property and disruption of infrastructure (D'Orsi, 2016). The neighborhood has high to very high levels of vulnerability in the overall index, as well as in three of the four SVI categories, the only exception is the household category, which shows low to very low levels of vulnerability.

Figure 22: Satellite image of Rocinha neighborhood (Google, 2021).

- Santa Teresa

The neighborhood is located in AP1 and has 30% of its total area in the zone of very high landslide susceptibility. Its occupation dates back to the 19th century. It has a total area of 515.7 acres, with 44% developed, mostly residential uses, and a mix of single-family and multi-family buildings. There are 15,323 households, and 40,926 residents, of which 46% identify as Black or Pardo. There are twenty communities classified as favelas, representing 37% of the total population (IPP, n.d.). Part of the neighborhood is classified in the plan for the Atlantic Forest conservation as a conservation area, and the rest is classified as sustainable use (Rio, 2015). Between 1966 and 2016 the neighborhood suffered five major landslides, which have caused a total of 121 deaths, as well as major property damage (D’Orsi, 2016). The neighborhood has a mix of Sectors of all vulnerability levels, but it mostly has medium to low overall social vulnerability. It shows medium to high levels of vulnerability in the built environment, and race and language categories, and it presents medium to low levels of household and socioeconomic vulnerability.

Figure 23: Satellite image of Santa Teresa neighborhood (Google, 2021).

- São Conrado

The São Conrado neighborhood is located at AP2, it has 57% of its total area in the zone of very high landslide susceptibility. It started being occupied in the 1930s, it borders the Tijuca National Park, and highway developments in the 1970s made it a high-traffic neighborhood. It has a total area of 648.9 acres, with 25% of it developed. There are 3,855 households, with a total of 10,980 residents, of which 17% identify as Black or Pardo. The neighborhood has mixed-use and a predominance of multi-family buildings. There are two communities classified as favelas, which represent 9% of the total population (IPP, n.d.). The neighborhood has small areas classified as conservation areas and sustainable use (Rio, 2015). In 1996 the neighborhood suffered two major landslides that caused major property damage and disruption in road access (D'Orsi, 2016). The neighborhood has very low levels of vulnerability in the overall SVI index, as well as in all the other categories, except for the built environment category, where the neighborhood shows high vulnerability.

Figure 24: Satellite image of São Conrado neighborhood (Google, 2021).

- Senador Camará

  Located in AP5, the neighborhood has 30% of its total area in the zone of very high landslide susceptibility. It was a sugar cane farm, and later a coffee farm in the 19th century, and now the old plantation house is a historic monument with an attached municipal park. The first subdivisions are from the 1950s, but the most intense development happened after the 1980s. The neighborhood has a total area of 1,690.9 acres, with 41% of it developed. There are 32,214 households, with a total of 100,169 residents, and 61% of them identifying as Black or Pardo. Senador Camará is mostly residential, with single-family houses. There are thirteen communities classified as favelas in the neighborhood, representing 38% of the population (IPP, n.d.). Almost half of its area is classified as a conservation area (Rio, 2015). Regarding the SVI, the neighborhood has medium to very high levels of overall vulnerability and medium to high levels of socioeconomic, household, and race and language vulnerabilities. For the built environment category, the neighborhood shows mostly medium and low levels of vulnerability.

Figure 25: Satellite image of Senador Camará neighborhood (Google, 2021).

- Urca

Located in AP2, the Urca neighborhood has 41% of its total area in the zone of very high landslide susceptibility. It has historic importance for being the location of the foundation of the city of Rio de Janeiro, in 1565, and encompasses the Sugarloaf Mountain. However, the neighborhood was only occupied at the beginning of the 20th century, after a series of landfills created space for development. It is currently a tourist hotspot, as well as the location of three universities. It has a total area of 231.9 acres, it is 32% developed, with mixed-used and mostly multi-family developments. There is a total of 2,550 households, with 7,061 residents, of which 17% identify as Black or Pardo. There is one community classified as a favela in the neighborhood, housing 244 people (IPP, n.d.). Most of the neighborhood is classified in the plan for the Atlantic Forest conservation as a conservation area (Rio, 2015). It has mostly low to very low overall vulnerability, with a mix of high to low vulnerability in all four SVI categories, except for the socioeconomic category, where it presents only very low levels of vulnerability.

Figure 26: Satellite image of Urca neighborhood (Google, 2021).

- Vidigal

Located in AP2, Vidigal has 83% of its total area in the zone of very high landslide susceptibility. It experienced its most intense development in the 1960s, and with most of the area classified as a favela, it became a symbol of resistance to favela removal in the late 1970s when the community was able to fight a removal project during the military dictatorship. It has a total area of 162.1 acres, and it is 34% developed, with mixed-use and mostly single-family developments. There is a total of 4,304 households, with 12,797 residents, and 59% identifying as Black or Pardo. There are two areas in the neighborhood classified as favelas, representing 81% of the total residents (IPP, n.d.). Only a small part of the neighborhood is classified as a conservation area (Rio, 2015). In the 1990s Vidigal suffered two major landslides, causing a total of ten deaths, as well as loss of property (D'Orsi, 2016). The neighborhood has mostly medium and high levels of overall social vulnerability. For the categories of the built environment, and language and race, it shows high levels of vulnerability, however, for the categories of household and socioeconomic vulnerability is shows low levels.

Figure 27: Satellite image of Vidigal neighborhood (Google, 2021).

As it is possible to notice, there is a great variation in the characteristics of the selected neighborhoods. While neighborhoods such as Leme and Urca show mostly low levels of vulnerability, others such as Mangueira and Rocinha present mostly very high levels of vulnerability. It is also interesting to notice that the selection of neighborhoods with the most risk includes historic areas as well as areas of very recent development. Even before the policy evaluation, it is possible to infer, based on the characteristics of the selected neighborhoods, that the city does not make an effort to prevent expansion to high-risk areas since these areas are occupied with all types of development.

Policy Scoring

After selecting the neighborhoods with the most risk, the policy evaluation was done. Results can be seen in Table 13 and Figure 28.

Table 13: Scoring of Policies by Neighborhoods

Neighborhood	Macrozones	FAR	Zoning	Sirens	Conservation Areas	Centralities	Housing	Total by Neighborhood
Água Santa	-1	-1	-1	-1	-1	1	1	**-3**
Alto da Boa Vista	1	-1	1	-1	-1	1	-1	**-1**
Barra de Guaratiba	1	-1	1	-1	-1	1	0	**0**
Camorim	1	1	1	-1	1	1	0	**4**
Cavalcanti	-1	-1	-1	-1	-1	-1	-1	**-7**
Complexo do Alemão	-1	-1	-1	1	-1	1	-1	**-3**
Engenheiro Leal	-1	-1	-1	-1	-1	-1	0	**-6**
Grajaú	-1	-1	-1	1	-1	1	-1	**-3**
Itanhangá	1	1	-1	-1	-1	1	-1	**-1**
Joá	1	1	-1	-1	-1	1	0	**0**
Leme	1	-1	-1	1	-1	1	-1	**-1**
Lins de Vasconcelos	-1	-1	-1	1	-1	1	-1	**-3**
Mangueira	-1	-1	-1	1	-1	-1	-1	**-5**
Rio Comprido	-1	-1	-1	1	-1	1	-1	**-3**
Rocinha	1	1	1	1	-1	1	0	**4**
Santa Teresa	1	1	-1	1	-1	1	-1	**1**
São Conrado	1	-1	-1	-1	-1	-1	-1	**-5**
Senador Camará	1	-1	1	-1	1	1	1	**3**
Urca	1	-1	1	-1	-1	1	0	**0**
Vidigal	1	-1	-1	-1	-1	1	-1	**-3**
Total by policy	**4**	**-10**	**-8**	**-4**	**-16**	**12**	**-10**	

Table 13: Scoring of mappable policies by neighborhood.

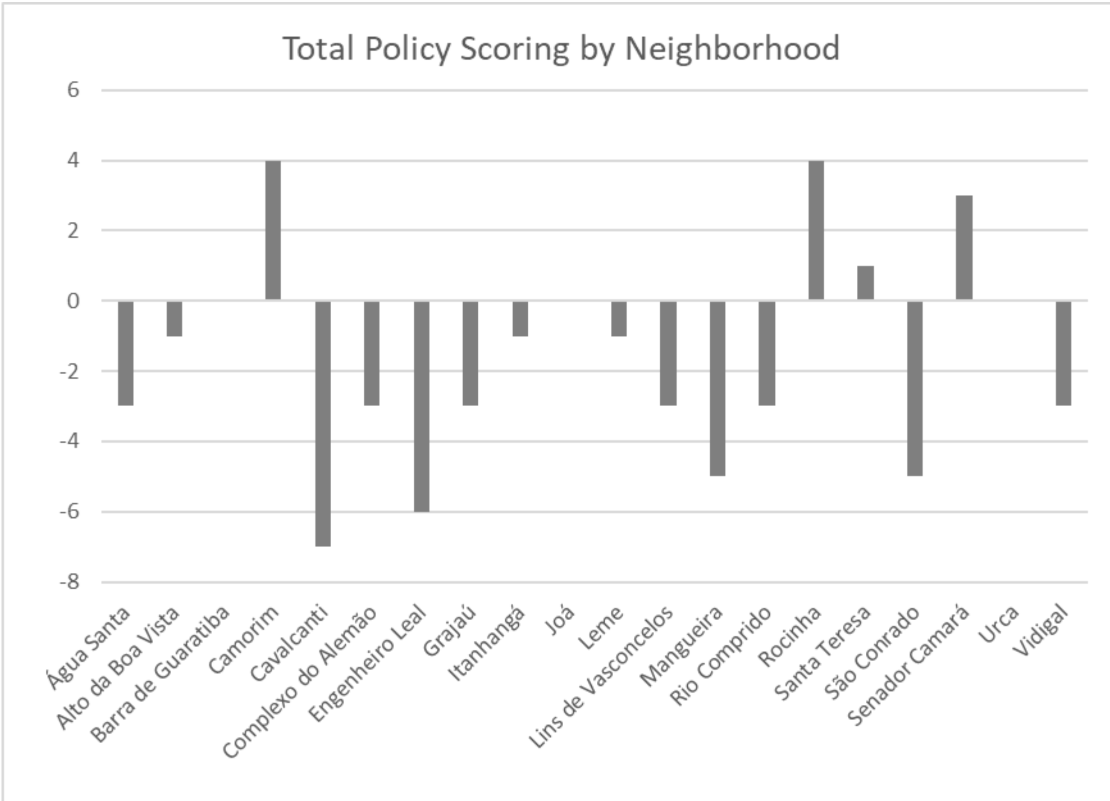


Figure 28: Graph showing policy scoring by neighborhood.

The neighborhoods were selected because of their percentage of area in high-risk zones, this way, they are not necessarily the most vulnerable, although they might encompass highly vulnerable Sectors. Additionally, as it is possible to see on Map 10, there are neighborhoods selected in all APs (maps zoomed-in into the neighborhoods showing SVI and Risk can be found in the Appendix). When analyzing the policies, most of the neighborhoods had negative scores, indicating that, overall the city is not attentive to landslide risk when developing policies. The neighborhoods with the lowest scores are Cavalcanti and Engenheiro Leal, which are bordering neighborhoods and received negative scores in all policies. Both have SVI scores between medium to very high, and a majority Black and Pardo population. The low policy scores in these neighborhoods raise concerns about environmental justice since the policies increase the vulnerability of already vulnerable populations. The second-lowest scores are from Mangueira and São Conrado neighborhoods, which have very different characteristics. Although both were developed at the beginning of the 20th century, Mangueira shows high levels of vulnerability, and a high concentration of Black and Pardo residents, while São Conrado has mostly low levels of vulnerability and a majority White population. The low policy score for both reinforces the idea that the city does not limit development in zones with high landslide risk, since even formal development is found in these areas, with little control of land use in risk areas. There are also equity concerns, the results indicate that the city does not adequately consider social factors while developing policies considering there is no indication of the policies trying to not cause negative impacts on vulnerable populations.

The neighborhoods with the highest scores are Camorim, Rocinha, Santa Teresa, and Senador Camará, with Rocinha and Camorim having the highest scores. Of the four, Rocinha is the only neighborhood that shows mostly high to very high levels of vulnerability, nevertheless, none of the neighborhoods shows mostly low to very low levels of vulnerability. The four neighborhoods have a mix of very low and very high levels of vulnerability. Rocinha and Santa Teresa have suffered major landslides between 1966 and 2016 (D'Orsi, 2016), which might indicate that the better policy result is due to response policies. Additionally, all four neighborhoods are of touristic interest, Senador Camará has a historic monument and municipal park, Santa Teresa is a historic neighborhood close to downtown, Camorim has a big area of environmental interest, as well as a convention center, and Rocinha regularly receives sightseeing tours (Riotur, n.d.). Rio is one of the most visited cities in Brazil, and has a major part of its economy dependent on tourism (Valente, 2019), this way, one possible conclusion from the policy evaluation is that the city might be more attentive to areas of touristic interest, possibly neglecting other neighborhoods.

The lack of relationship between the SVI scores and the policy scores indicates that, when developing policies, vulnerability is not considered. This is not surprising since, through this research, no work was found that mapped social vulnerability within any city in Brazil. Additionally, throughout the plans, it is possible to notice that only favelas are assumed to be in risk areas and considered for relocation. In the Comprehensive Plan, for example, when listing plan guidelines it is stated that the city has the goal of urbanizing favelas except in areas of environmental protection or where there are environmental risks, but there are no guidelines for formal development that occupy high-risk areas (Município do Rio de Janeiro, 2011, Art. 3º). As seen in the previous sections, most favelas are not located in high-risk areas, and many high-risk areas are occupied with formal development.

The inconsistent policy scoring between the neighborhoods also suggests that there might not be a strong effort in the city to integrate their policies that regulate land use. The policy where most neighborhoods received a negative score was Conservation Areas, which indicates the city does not do a good job in controlling development in those areas, and that they were defined without consideration of other land-use factors.

This is particularly problematic since development in these areas increases deforestation, consequently increasing the exposure to landslides. Although the conservation areas are focused on the protection of the Atlantic Forest, establishing all high-risk areas as conservation would add another layer of restriction, avoiding deforestation and preventing people from living in these areas.

Most neighborhoods also received negative scores for FAR and Zoning, indicating that, when developing these policies, there was no consideration of landslide risks since they incentivize development in high-risk areas. For FAR the Comprehensive Plan sets one standard for the entire neighborhood, which is not desirable considering there is a great variation in the area of each neighborhood, and some may need more than one FAR ratio depending on the part of the neighborhood. For most neighborhoods FAR induces high-density development, which is not desirable in landslides areas. Additionally, most Zoning classifications did not consider other regulations, such as conservation areas, with some areas listed as conservation but zoned as residential, for example. Also, there are residential developments in the restricted areas, which are those above the 100m level curve. Finally, the dates of the zoning policies imply that the city does not reassess its zoning policies, adequating the policy to the current uses, and not guiding which future uses are adequate for each region. Zoning should help guide future development, and the city could employ it to limit the occupation of high-risk areas (Islam & Ryan, 2015).

The location of Civil Defense Sirens also received mostly negative scores, which indicates that most places that should have sirens do not have them. When looking at data regarding historic landslides (D'Orsi, 2016), the location of sirens coincides with them, which suggests that sirens are only installed after major events have already caused loss of life and/or property. Additionally, there are only sirens in the East part of the city, in AP1, AP2, AP3, and East of AP4, which might indicate that AP5 and West of AP4 are neglected by the Civil Defense. Even with major landslides happening in these areas there are no sirens installed.

Finally, it is important to notice that when looking into the maps for these policies they do not always correspond with all occupied areas. When looking into the map of current land-uses (Data.Rio, 2019f) some areas showing residential uses appear as empty in Zoning maps or as protected in the Conservation Areas map. The lack of alignment between the policies and maps shows a lack of analysis of the current situation since current uses appear to be ignored in some areas of the city. It also indicates a lack of integration of plans, with maps showing conflicting information. Looking into the policy results and maps produced by the city, there seems to be a disconnect between the different city departments, and no internal effort to make the policies work together.

Plan Evaluation

While scoring the individual policies it was also important to evaluate the general quality of each of the plans. First, it is possible to notice a general lack of community engagement, there was no indication of the inclusion of local knowledge in any of the plans, which can hinder plan quality and implementation. This indicates that planning in Rio still has a top-down approach, with policymakers and practitioners making decisions without consulting with the local communities. Additionally, as mentioned previously, it is possible to notice a lack of alignment between plans and policies developed by different departments, showing a lack of integration.

The Comprehensive Plan, which sets development standards for the future. It lacks elements of good quality plans, it is written as a law, with mostly programmatic actions. Although there are goals, there is a lack of timelines, and measuring tools, and many policies listed in the plan are not mappable or grounded in spatial aspects. Also, the plan lacks analysis of the current situation and heavily relies on further legislation for its proposed actions, which suggests that there is no effort to implement these plans and that most decisions are done based on pre-conceived ideas of policymakers.

For example, Art.11 and Art.12 of the Comprehensive Plan establishes the Investment and Development Attraction Hubs (PADES), which would be located along major roads, and be further defined in regional plans (Município do Rio de Janeiro, 2011). However, there is no specification regarding when the establishment of PADES or the regional plans should be finished, and who is responsible for developing them. Also, during this research, it was not possible to find the regional plans referred to in the Comprehensive Plan, which indicates that they either were never developed or never published for public consultation. Another example is when the plan establishes guidelines for dealing with water resources (Município do Rio de Janeiro, 2011, Art. 171). It states that it is the responsibility of the relevant agencies for environmental management to implement the Municipal Program of Water Resources Management, however, no timeline for when the program should be implemented is defined, and no guidelines about how to do it. There are also no measuring tools to evaluate if the water resources program is being successful, or if there are goals to be achieved with it (Município do Rio de Janeiro, 2011). Although there are more specific items, such as Art. 117 which identifies areas of environmental interest, most of the plan focuses only on what policy-makers should consider when developing complementary policies (Município do Rio de Janeiro, 2011).

To be sure, it is expected that complementary plans and policies will be necessary after a comprehensive plan, nevertheless, timelines, specific goals, and measuring tools are elements that should be included in all plans to increase their effectiveness. The low quality of the Comprehensive Plan reflects the study done by Santos Junior & Montandon (2011), where the lack of elements of good quality plans is seen across the country. Additionally, this reinforces the idea proposed by Villaça (1999) that plans in Brazil are developed not to be implemented. In Rio's case, the plan seems to be made only to meet federal requirements.

The Land Use and Zoning policies are the most objectives of the ones evaluated. There is a zoning map for the entire city, but many neighborhoods have specific zoning regulations found in separate documents. During the research for this thesis, a final plan defining the zoning and land-use regulations for the entire city was not found, only proposed bills. What was found were separate documents with the specifications for some neighborhoods, and a map with the current zoning. Additionally, the neighborhood plans are limited to explaining the definitions of each zoning category, what uses are permitted, and the limits of each zone. This reinforces Villaça's (1999) argument that zoning is the only planning document reinforced in Brazilian cities since the documents found seem to be made to serve as a legal reference for developers and city officials, they are not plans.

Although the policy scoring for Conservation Areas was mostly negative, the Plan for the Conservation of the Atlantic Rainforest (Rio, 2015) is the best of the ones analyzed, it has a good analysis of the current situation as well as listed goals and timelines. The plan includes maps and tables explaining the current state of the city, population and occupation trends, analysis of environmental and geologic characteristics, and analysis of climate change impacts and risk of floods and landslides.

The plan also includes a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis, relating to the conservation of the Atlantic Forest in the city, and an analysis of different future scenarios. For each of the plan's guidelines, there are specific tasks, expected results, indicators to be used, level of priority, justification for the action, goals, expected timeline, which institutions will be involved, who will benefit, where funding is coming from, and legal requirements associated with that action. The low scoring for the conservation areas is related to the fact that, in many areas in the city, the high-risk areas are not included as conservation areas. That is understandable considering the focus is on the protection of the Atlantic Forest, however, including risk areas in the conservation areas adds another layer of restrictions that would benefit people and the environment. This way, the low scoring indicates a lack of integration between departments.

When doing the policy scoring and evaluation the neighborhoods with the most risk were selected. As it was possible to notice, this included neighborhoods with very different characteristics, which suggests that landslide risk and vulnerability are not determinant factors for policymakers and practitioners. It was expected that SVI was not contemplated in policies, considering no efforts were found that applied it to the Brazilian context, however, there were also no patterns related to socioeconomic or race distribution, which was surprising. This might be partially a positive sign since it shows there is no bias against low-income or Black and Brown populations in the policies. However, it mostly indicates the neglect of equity issues, with policies not considering disparate impact in vulnerable populations.

Further, the lack of consideration of landslide risk in the policies is very concerning. The city has a long history of landslides, and although plans and policies acknowledge it, multiple types of development are found in high-risk areas, not only informal development. When looking at the maps it is possible to notice that risk knowledge is not translated into policies and practice. Although the city has monitoring mechanisms, such as the alarm system, the AlertaRio system, and COR, there is a lack of mitigation and prevention strategies. This again brings equity concerns, since the most affected by the lack of action will be the most vulnerable populations.

Finally, the issues discussed in Chapter 1 regarding local planning in Brazil are reinforced after this analysis. There is generally a lack of good quality elements in the Comprehensive Plan, and it seems that they are not intended to be implemented. There is also a lack of public engagement, which reinforces equity concerns. With local planning adopting mostly a top-down approach, policymakers and practitioners might not be aware of local problems and enact inefficient policies, or harmful policies. Additionally, the lack of participation might make it harder for plans to be implemented.

Chapter 4: Recommendations

The city of Rio de Janeiro is densely populated, and many established areas coincide with high-risk areas, nevertheless, moving forward there is room for the city to improve landslide mitigation and resilience. The most effective mitigation strategy would be to take people out of the high-risk zones, however, around 109,000 people live in Census Sectors with 90% or more of their area in the high-risk zone. Finding places to relocate this population, and do it equitably, requires great governance capacity as well as funding. Additionally, this would not be achieved without financial support from State and Federal governments. The city could have a specific task force to study the feasibility of relocating people, which would identify the areas of most risk and areas where resettlement is possible, as well as develop an expected budget to negotiate with the other levels of government. Further, biases against favelas must be addressed, and areas selected for buyouts should be considered based on risk, even if it means dislocating high-income people.

Buyout programs, where parcels are bought by the government to become permanent open areas, have become a fairly common solution in the USA for flood-prone areas. For example, between 2000 and 2017 Houston, TX, has bought more than 3,000 properties that were located in hazardous areas (Loughran & Elliott, 2019). One successful example of this type of policy is the case of Cedar Rapids, IA, where after a major flood in 2008, the city acquired more than 1,300 properties and was able to redevelop its riverfront. In the buyout areas, the city was able to build a greenway as well as flood protection infrastructure (Tate et al, 2016). Relocation has the benefit of taking people out of risk while creating green and open areas, and increasing areas of environmental protection. In Rio, it could also be used to recover some of the areas of the Atlantic Forest. However, it is important to consider disparate impacts to vulnerable populations, in the case of low-income populations, relocation needs to be associated with public and affordable housing projects, and residents should not be removed without a clear plan for where they will move to.

The city should also start using social vulnerability as a factor in its policies. In the present work, CDC's SVI was adapted for the Brazilian context, however, when analyzing vulnerability within the city the indicators for the built environment category did not seem relevant. There were no big differences in infrastructure quality within the city, and the selected indicators seem to be more relevant when comparing municipalities across the country. Although it is important to understand how the city ranks country-wide in terms of vulnerability, other indexes or indicators could be used that are more adequate for comparing Census Sectors or neighborhoods within cities. For example, access to transit, access to paved roads, and the legal status of the property could be used to determine built environment vulnerability.

Another area of improvement is in plan quality. First, the lack of analysis of the current situation in the Comprehensive Plan and Land Use and Zoning policies indicates that many decisions are being done based on preconceived notions of policymakers. A comprehensive analysis considering demographic and social factors, such as the SVI indicators, and risk is important to have less biased decisions. There should also be the inclusion of local knowledge, improving solutions, and implementation strategies. By doing this the city can evaluate its policies by the impact they may cause to vulnerable populations, and either rethink them or develop actions to mitigate the disparate impact. The city could also use SVI to guide investment to areas of high vulnerability that are not high-risk areas. For example, the State of Texas has been using SoVI as one factor for allocating disaster mitigation funding, making it more likely for areas of the state with high vulnerability to receive funding (GLO, 2020).

It is also important to include clear goals, timelines, and tools in the plans. A deeper analysis of the current state of the city would help legislators come up with goals and timelines, making it possible for the plans to be implemented. Although there are good instruments and aspirations listed in the plans, such as progressive taxes, and restriction of development in areas above the 100m level curve, the lack of basic elements of plan quality makes them inapplicable. The inclusion of local knowledge and efforts to increase community engagement should also improve plan quality, and make it easier for policies to be reinforced.

Additionally, the city's plans should be more grounded in spatial elements, having mappable and place-specific policies, and better integration of policies. The city already has a great repository of maps, which show zoning, conservation areas, risk areas, etc., however, policymakers need to make use of these maps when making decisions. By looking into the existing maps it is possible to notice incongruencies, such as areas zoned for residential use that are also classified as conservation areas.

The city is currently reformulating its comprehensive plan, which presents it with a unique opportunity to make these changes. Furthermore, the city should make an effort to integrate its plans. As the policy and plan evaluation shows, the current plans are not well aligned. The Plan Integration for Resilience Scorecard (Malecha et al., 2019) could be used by each department when developing new policies. This way, for example, when defining neighborhoods' centralities, these are not located in high-risk areas.

Finally, it is important to point that the landslide susceptibility map only has three risk zones, and the present work only considered the highest level of landslide susceptibility for the plan evaluation. Areas of medium susceptibility are also important to be considered, and land-use policies should only allow development that does not increase risk in these areas. Further, other environmental threats were not considered in this work. The city also experiences floods, and sea-level rise, which poses major threats to the population, and should also be considered in plans and policies.

Chapter 5: Final Remarks

The issue of disasters brings many political and social discussions, and to fully address it many concepts need to be considered. Resilience is one of the most important ones, it focuses on creating adaptation strategies to climate change and disasters by understanding that different spheres of human existence, from the natural environment to social relations, are interconnected. A second important concept when studying disasters is vulnerability, which has no precise definition but relates to preexisting social, political, economic, and physical characteristics of a place. The concept links social inequalities built by historical processes to the probability of suffering disasters. This way, it is possible to understand that disasters are not caused by the impact of hazardous events, they are social processes that put citizens, normally low-income and people of color, in situations of high risk.

In the city of Rio de Janeiro, it is clear that disasters are a result of rapid and unequal spatial development, discriminatory and technocratic policies that forced low-income and Black and Pardo people to occupy inadequate areas, institutional fragility, and patrimonialism that generates corruption and violence. This inequitable situation results in the State of Rio de Janeiro having the highest material loss by disasters in Brazil, and fatalities caused by floods and landslides are an unfortunate pattern. After analyzing the vulnerabilization process of the city, questions regarding what can be done about the issue remain. Resilience building can be one way of moving forward since it is a comprehensive approach that encompasses adaptation and mitigation strategies.

As an initial step in the process of resilience building, the present research had the goal of mapping and analyzing social vulnerability and landslide risk in the city of Rio de Janeiro, and evaluate local plans in their ability to decrease vulnerability. For this, the CDC's SVI was adapted for the Brazilian context, the social vulnerability was mapped by Census Sector, and the risk map was provided by GeoRio. To analyze the plans the Plan Integration for Resilience Scorecard was used as a reference, and the mappable policies that determine land use were selected. The neighborhood was chosen as the geography of analysis, and twenty neighborhoods were selected based on the proportion of their area in the risk zones. A score was given for each policy in each neighborhood based on its potential to increase or decrease vulnerability.

The analysis shows that the city's historic segregation patterns are reflected spatially, with AP2 having low levels of overall vulnerability, as well as low vulnerability in each specific category (Socioeconomic, Household composition, Race & Language, Built Environment). AP5 showed the highest vulnerability levels in all categories. Other APs showed mixed levels of vulnerability, however, mostly average to very high vulnerability. It is important to notice that, although there is a certain concentration of highly vulnerable Census Sectors in risk areas, they are spread out around the city. When calculating the relationship between the indicators and risk areas, none showed a very strong correlation but, as expected, income and race were some of the indicators with the strongest relationships to risk. Less expected relationships were found such as educational attainment and age.

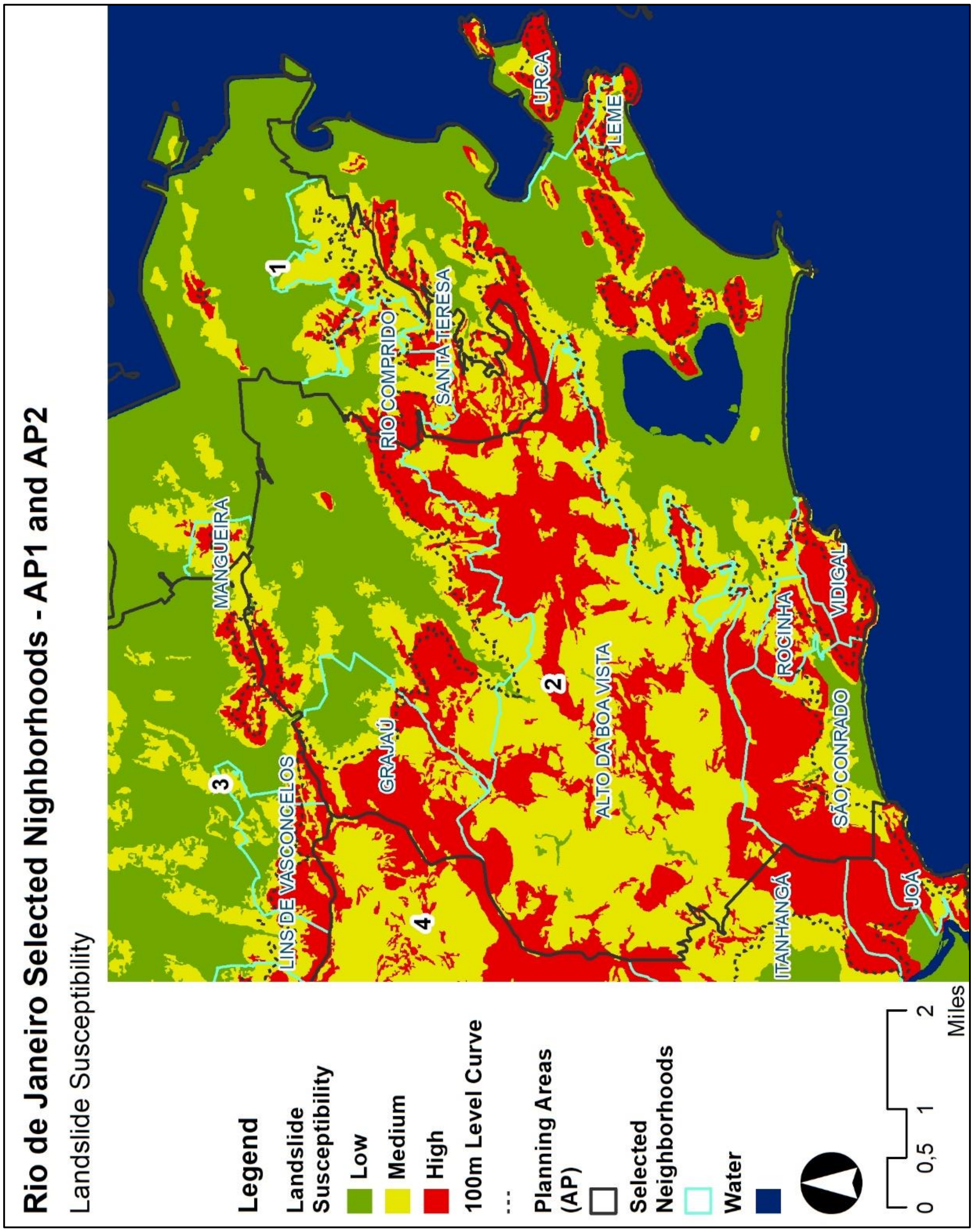
When scoring the policies that regulate land use the results suggest that social vulnerability and risk were not adequately considered by policymakers when developing them. There was no clear relationship between a neighborhood's score and their level of risk or vulnerability. There was a general lack of plan quality, and most elements of the analyzed plans were only programmatic, without clear goals or timelines. These results back the reflections done by Villaça (1999) that plans in Brazil are not developed to be implemented, being done only to fulfill legal requirements. Additionally, lack of public participation raises social justice concerns.

The city has institutions in place with the goal of monitoring risk, such as COR and Alerta Rio, however, there is still space for improvement. Making better plans, with goals and timelines, that address social vulnerability and risk, and include local knowledge, could help build resilience in the city. When developing new plans, all departments should consider hazard mitigation and social vulnerability, making sure their policies do not increase risk and do not have disparate impacts in disadvantaged communities. Also, departments need to have plans that complement each other instead of being contradictory.

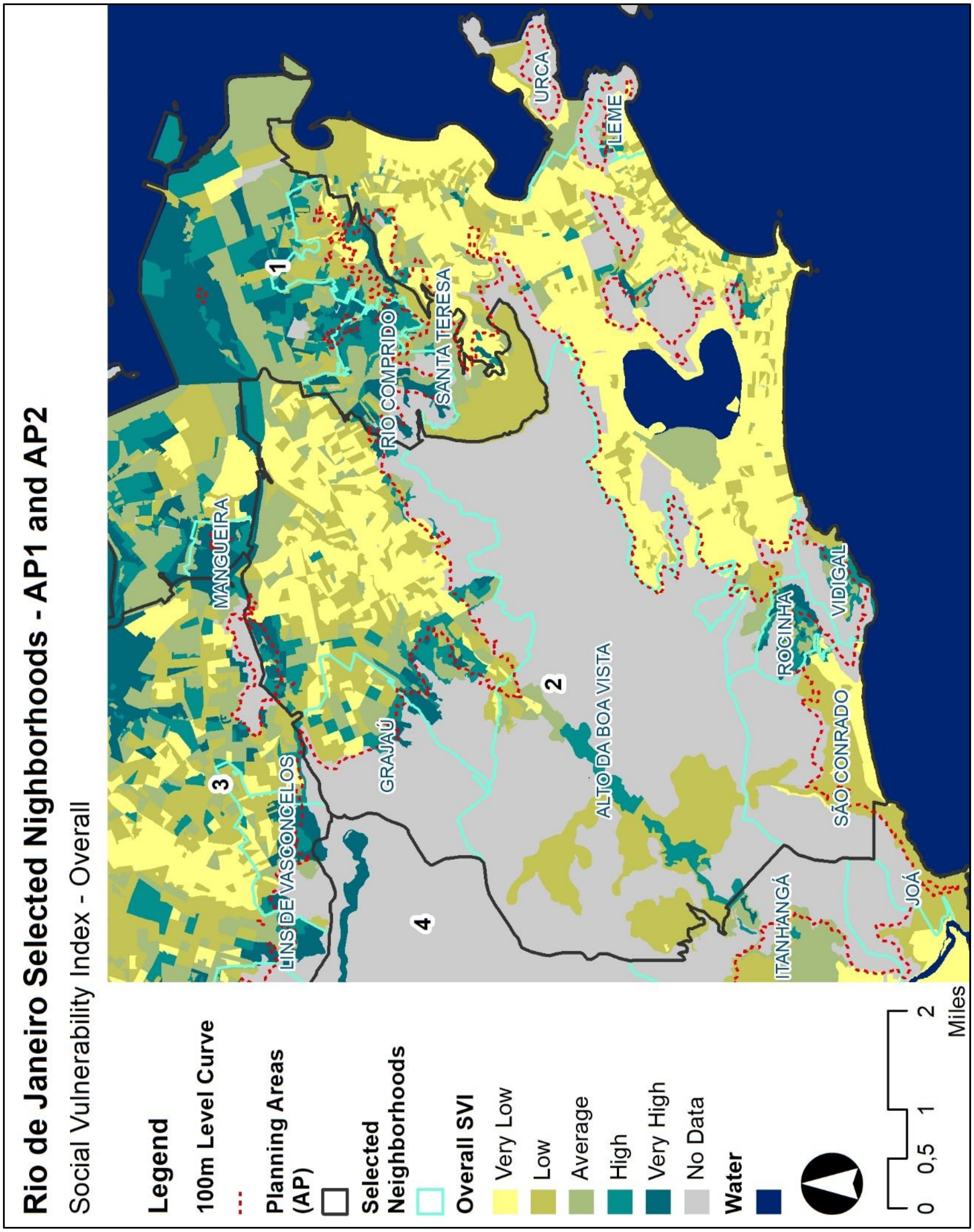
There are many possibilities for future research. First, more research about mapping social vulnerability in Brazil is necessary, although efforts were found that compared all the country's municipalities, no references were found that mapped social vulnerability within a Brazilian city. Additionally, there needs to be more research regarding plan quality in Brazil. The lack of literature about this specific area in planning might be due to the relatively recent re-democratization of the country however, there has been a lot of progress in the last thirty years that makes plan evaluation an area to be further explored.

Resilience building is an essential task for cities in the 21st century. As climate change worsens, and environmental hazards become stronger, cities need to find ways to adapt and be more sustainable. This needs to be done with equity concerns in mind since environmental issues have been used before to enact policies that cause disparate impact to vulnerable populations, and resilience building cannot be done by only considering the most well-off. The city of Rio de Janeiro has a long history of landslides and floods and has been working to become more sustainable and adapt to climate change. Nevertheless, many actions have stayed on paper, and there need to be greater efforts to put policies into practice. Although a hard task, it is a necessary endeavor for the city to thrive in the future.

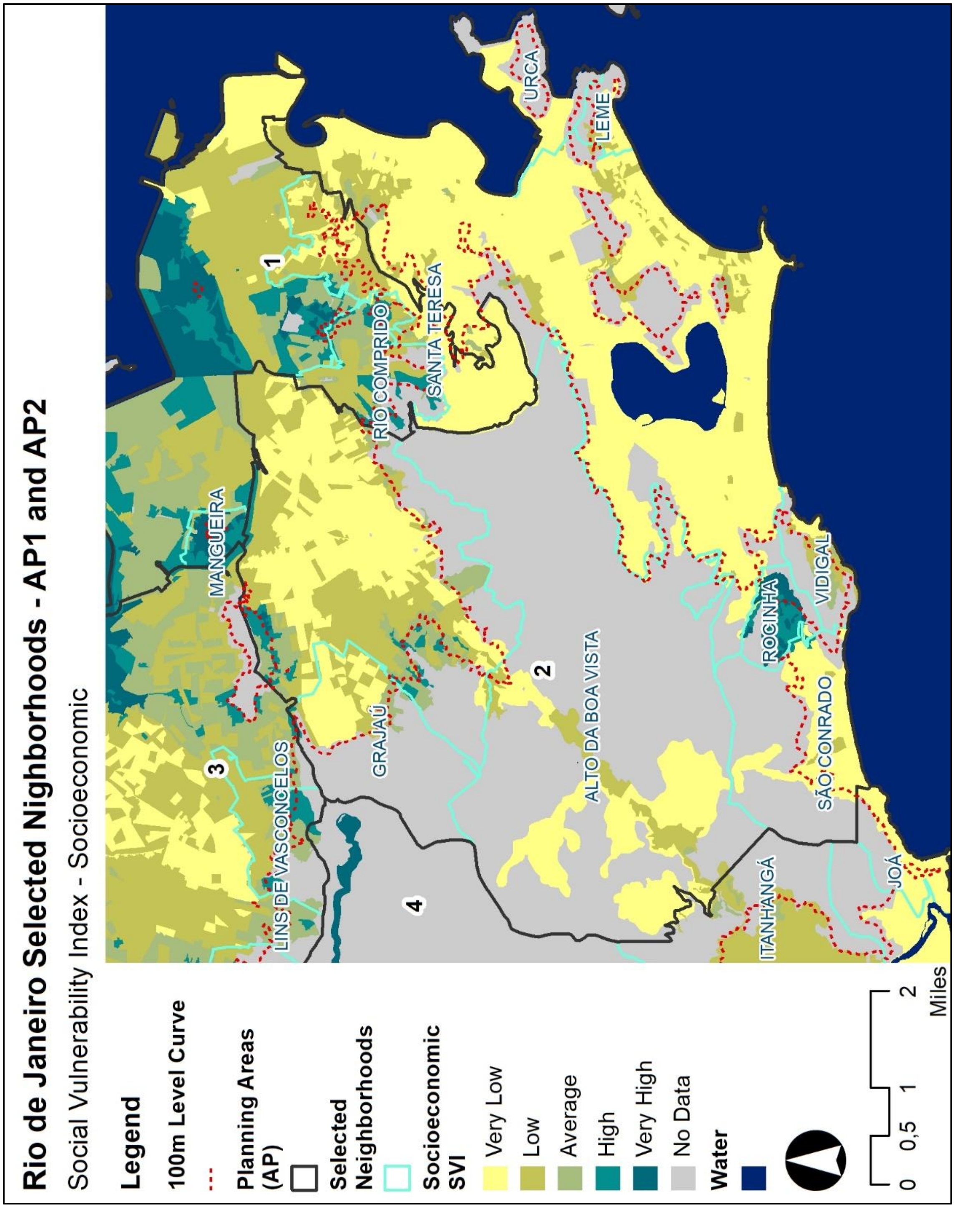
Appendix



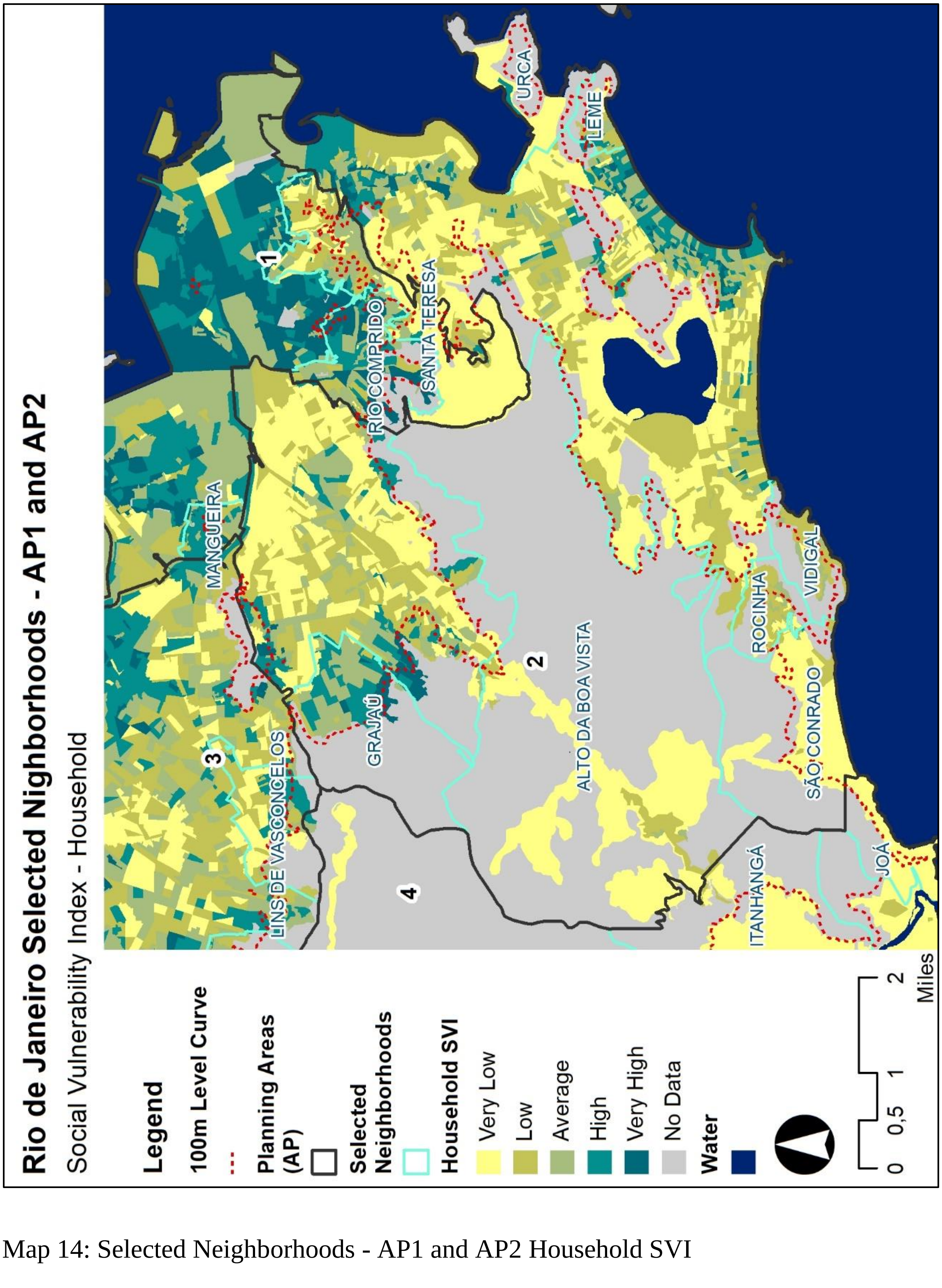
Map 11: Selected Neighborhoods - AP1 and AP2 Landslide Risk.



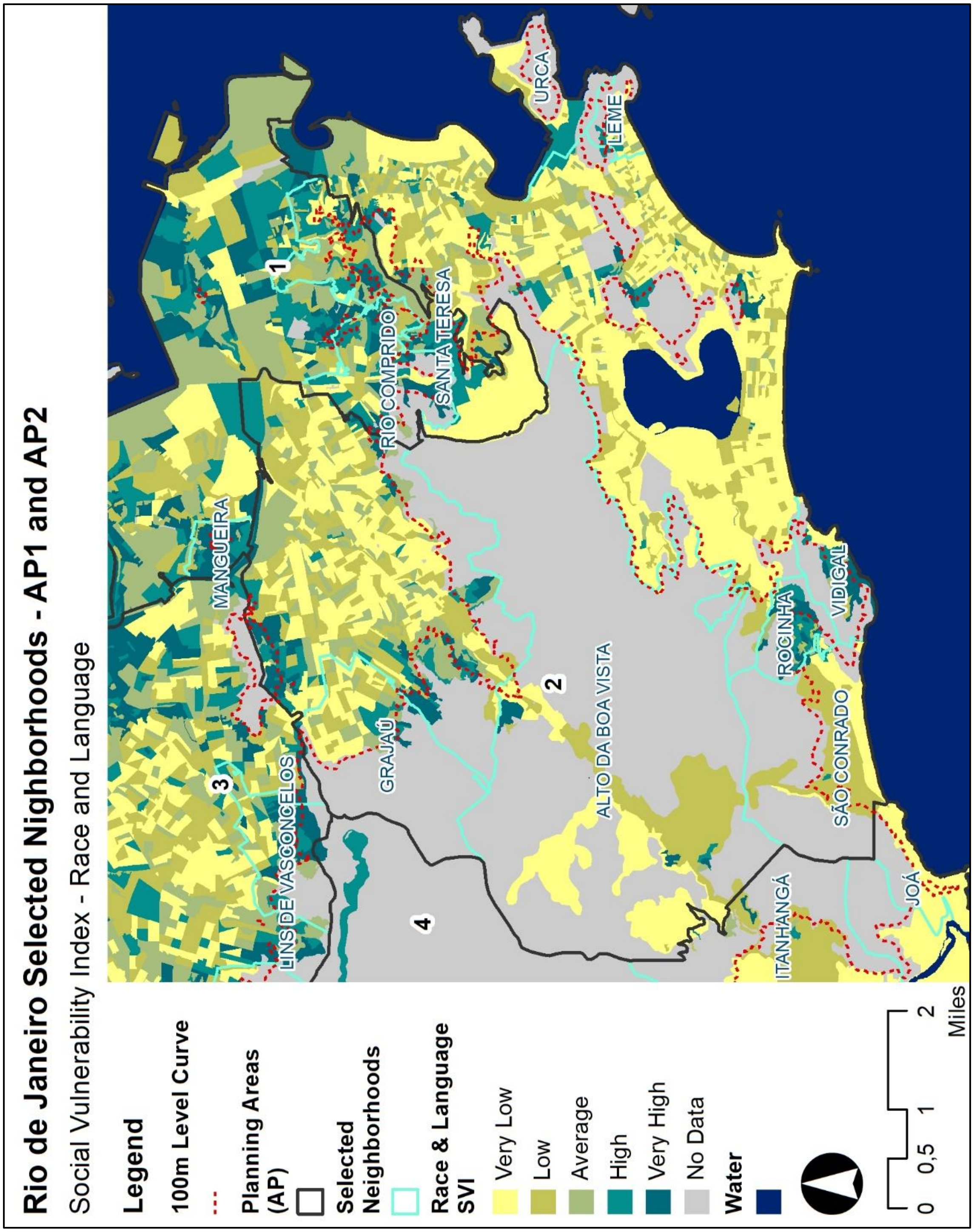
Map 12: Selected Neighborhoods - AP1 and AP2 Overall SVI



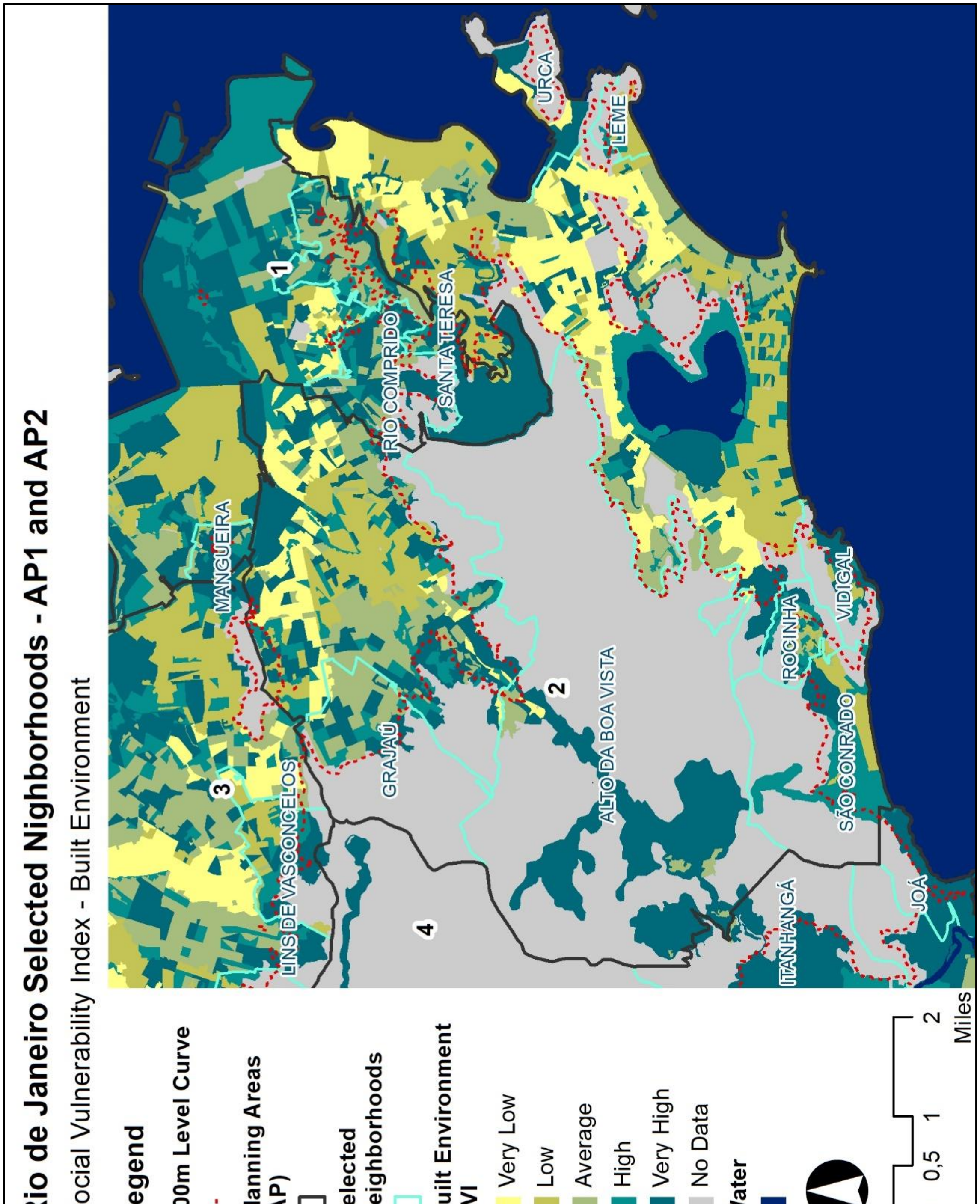
Map 13: Selected Neighborhoods - AP1 and AP2 Socioeconomic SVI



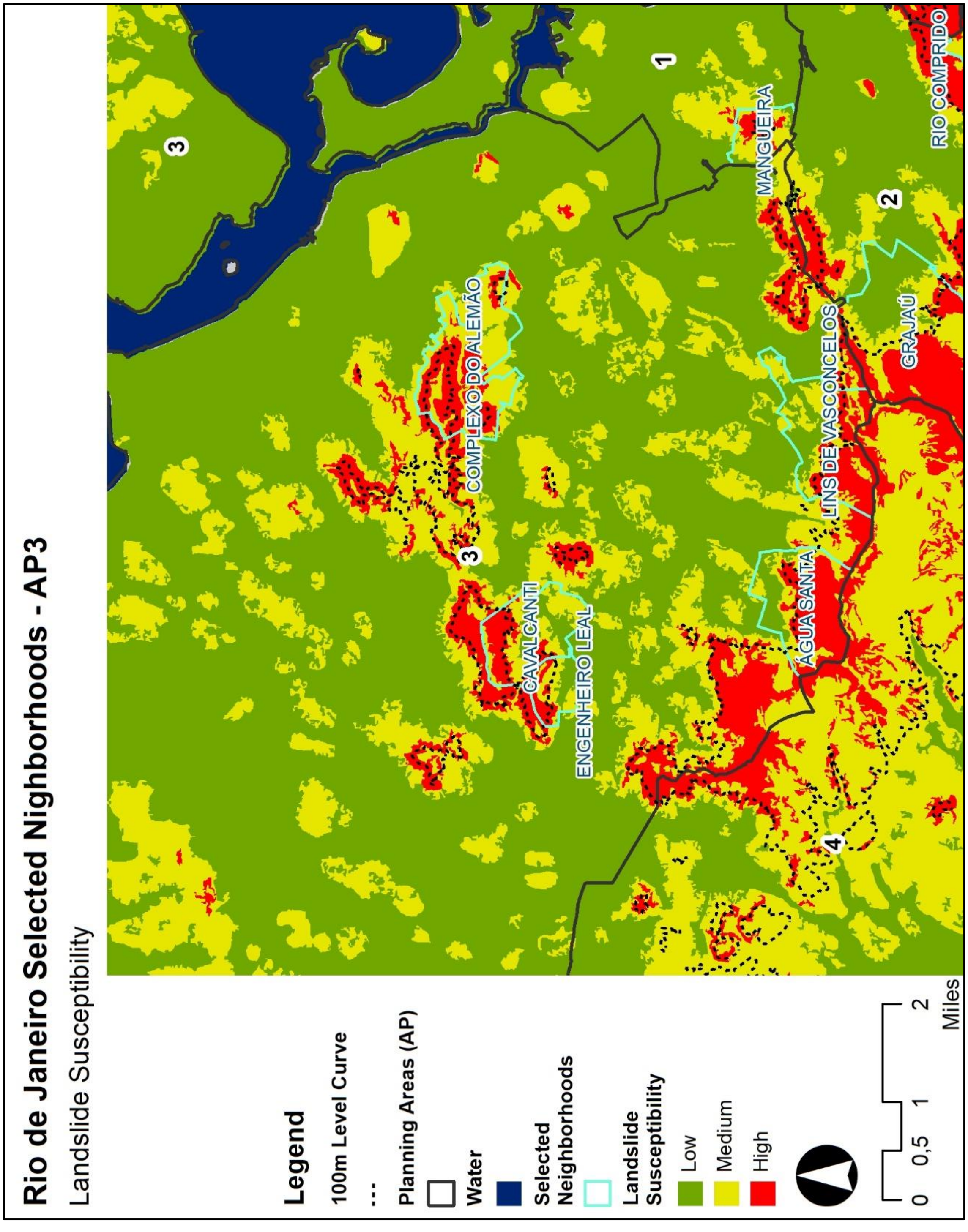
Map 14: Selected Neighborhoods - AP1 and AP2 Household SVI



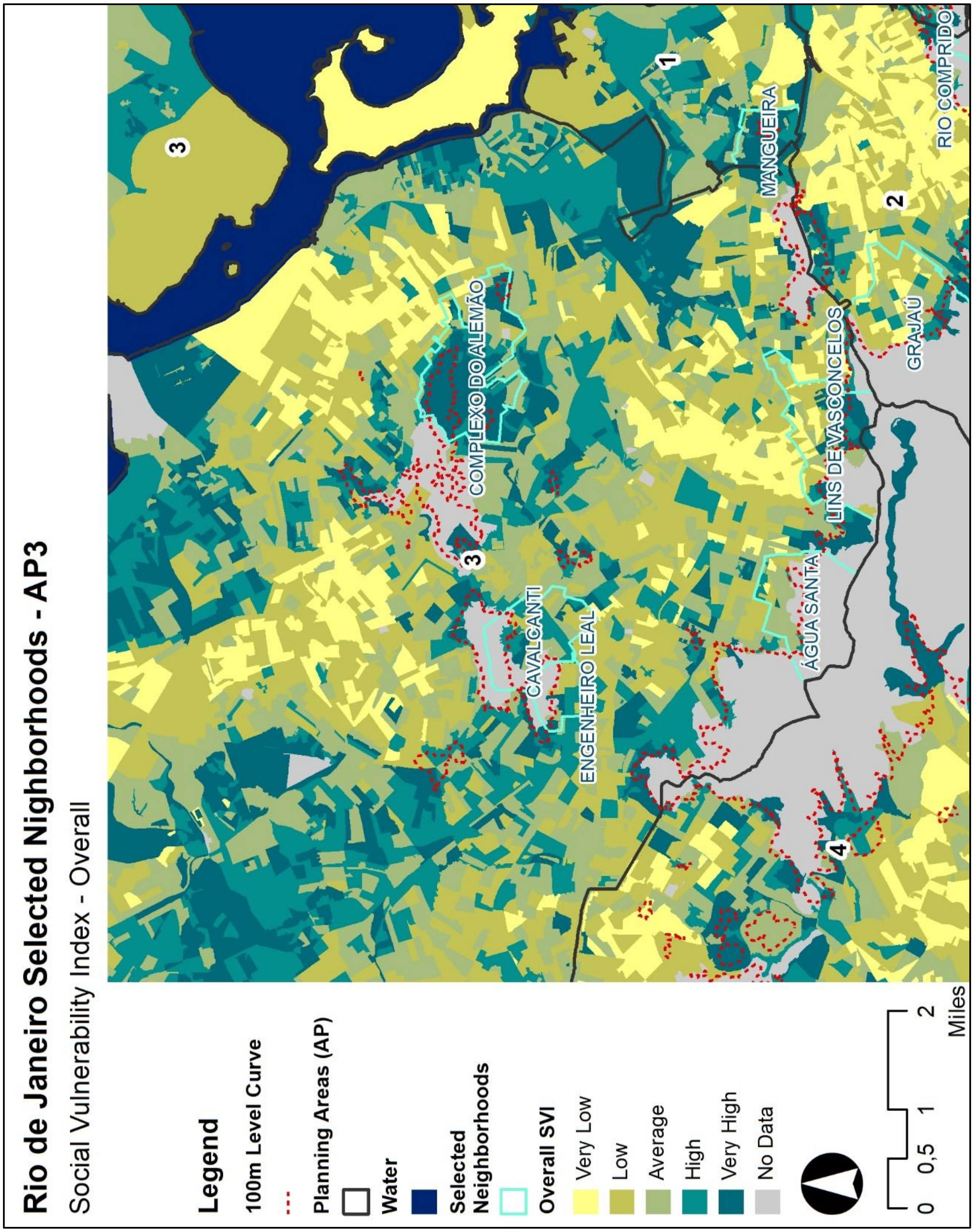
Map 15: Selected Neighborhoods - AP1 and AP2 Race and Language SVI



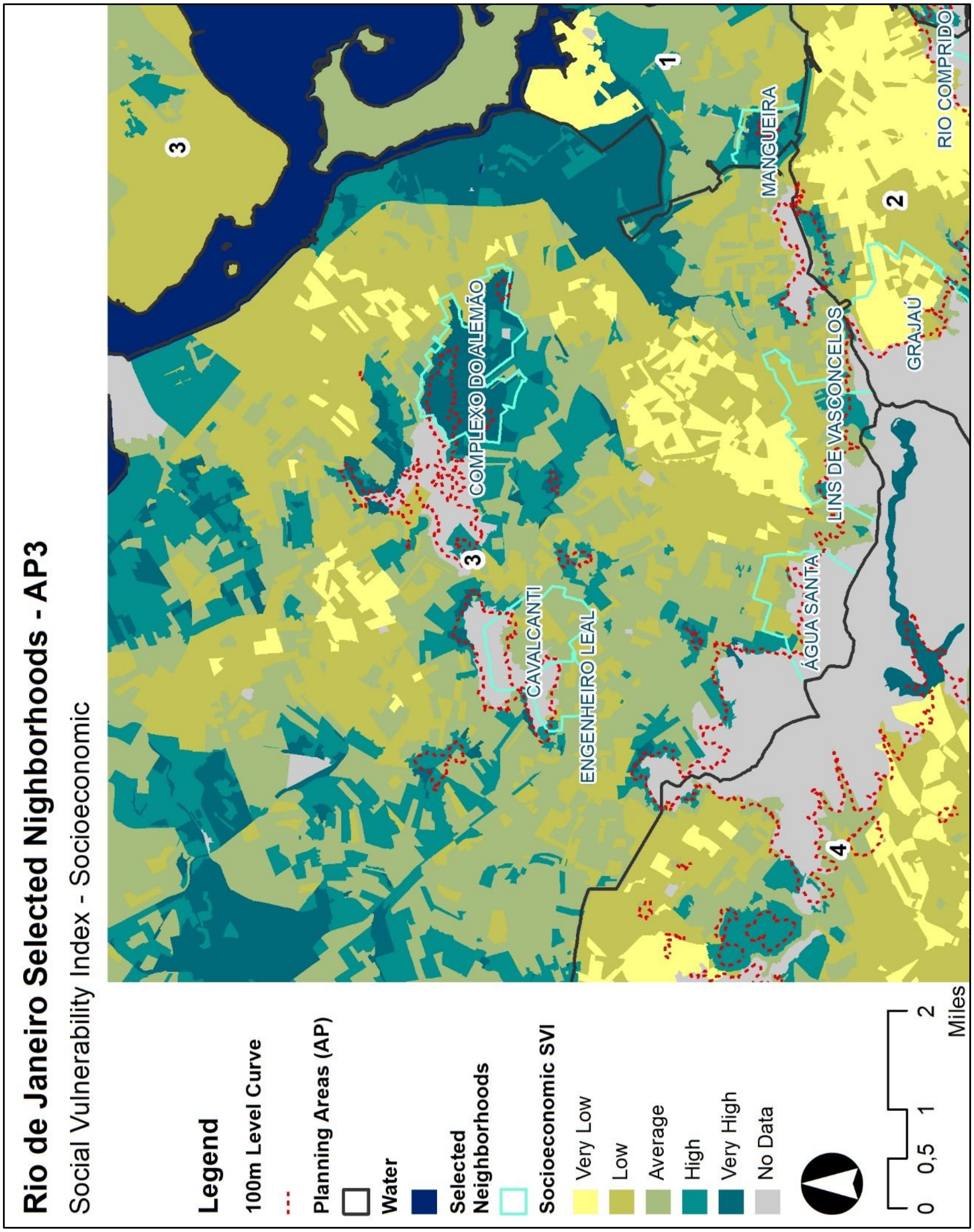
Map 16: Selected Neighborhoods - AP1 and AP2 Built Environment SVI



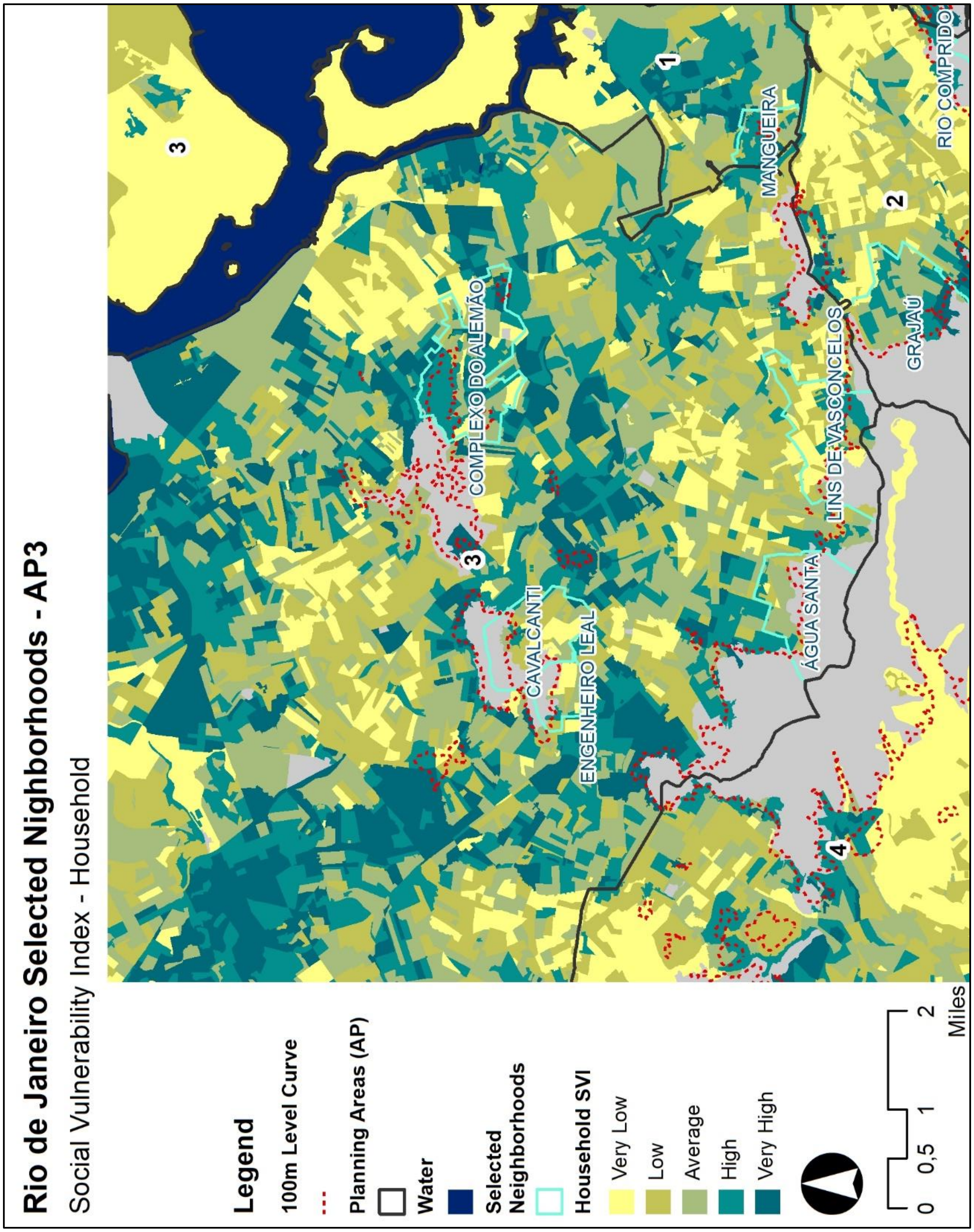
Map 17: Selected Neighborhoods - AP 3 Landslide Risk



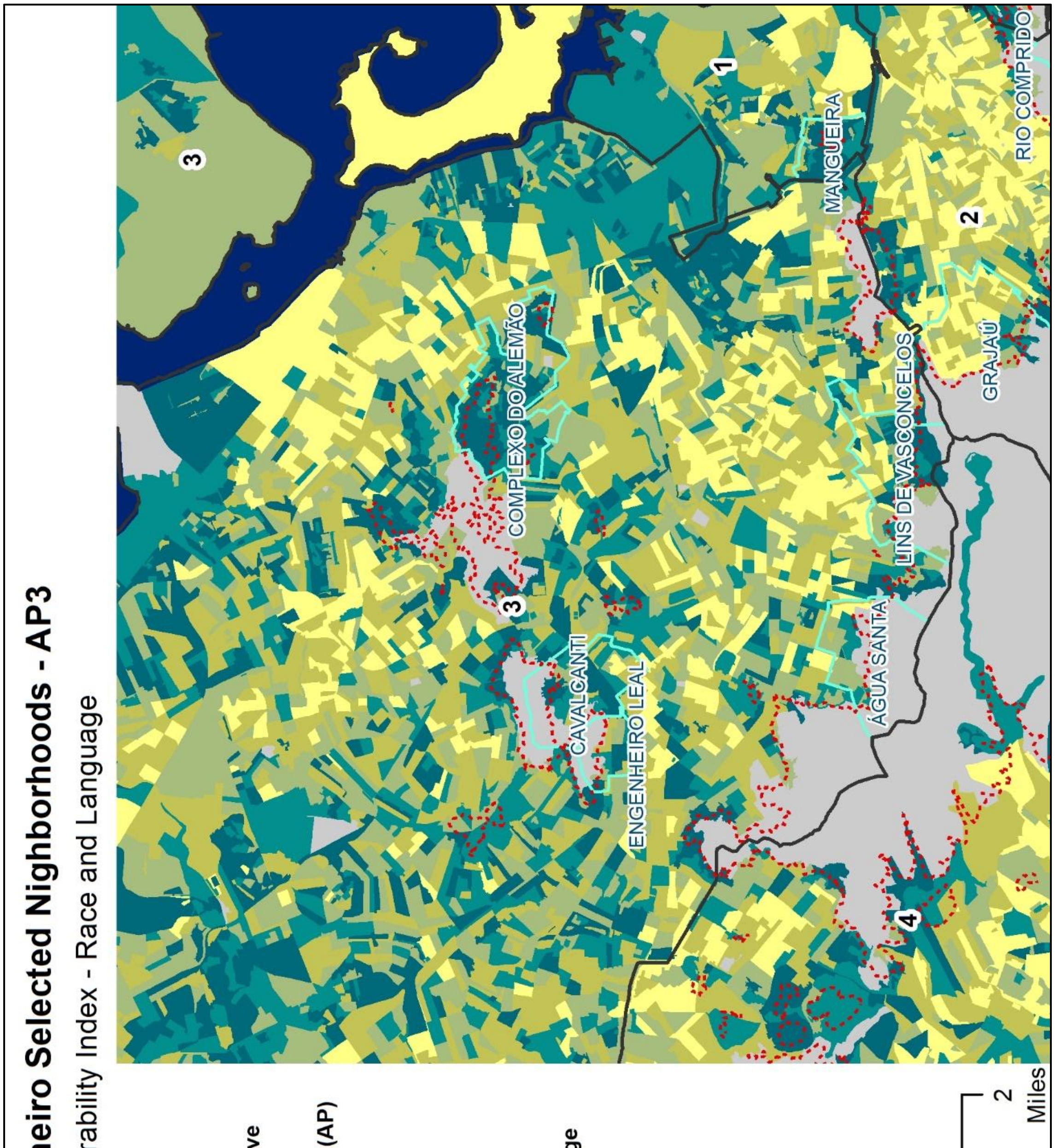
Map 18: Selected Neighborhoods - AP3 Overall SVI



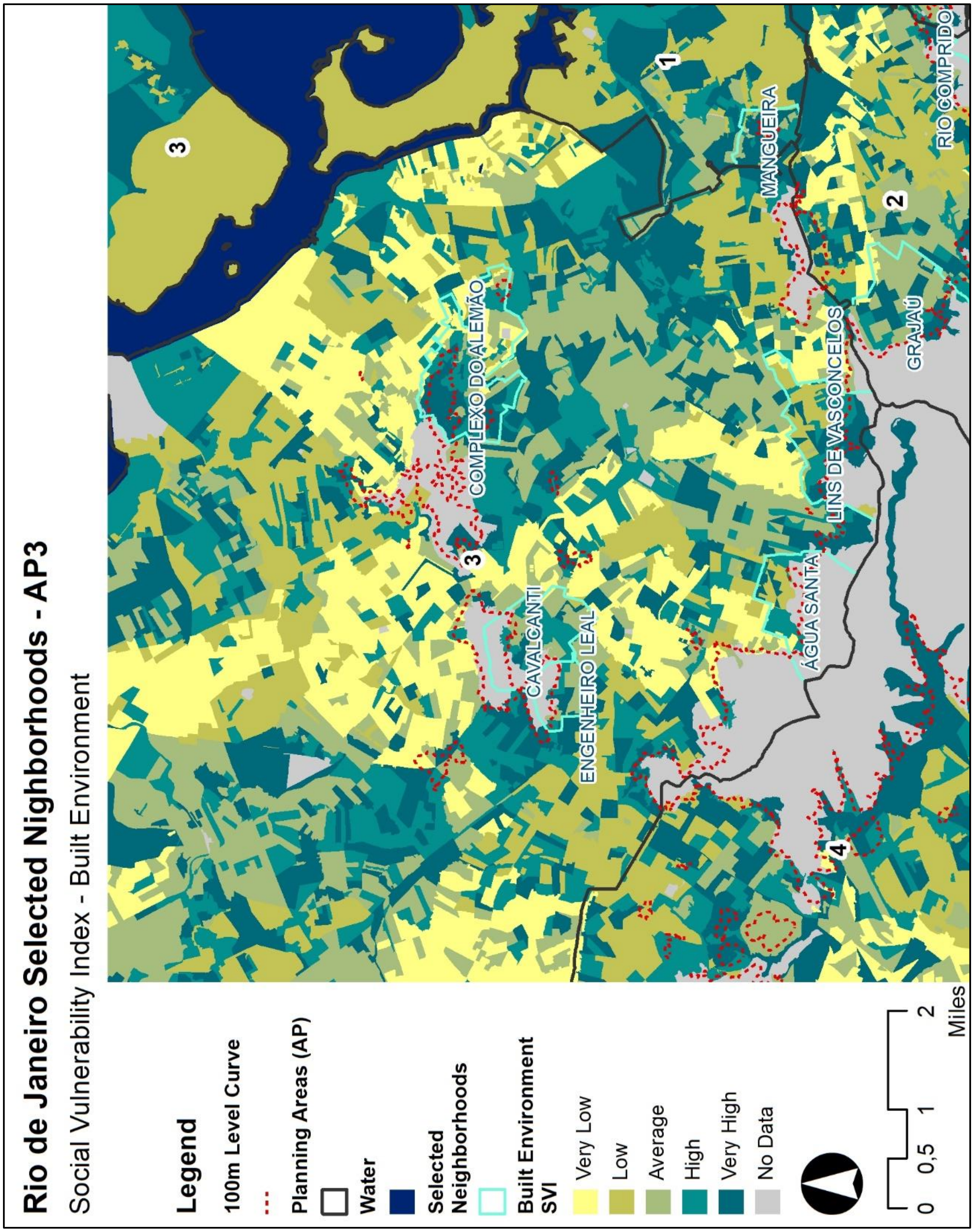
Map 19: Selected Neighborhoods - AP 3 Socioeconomic SVI



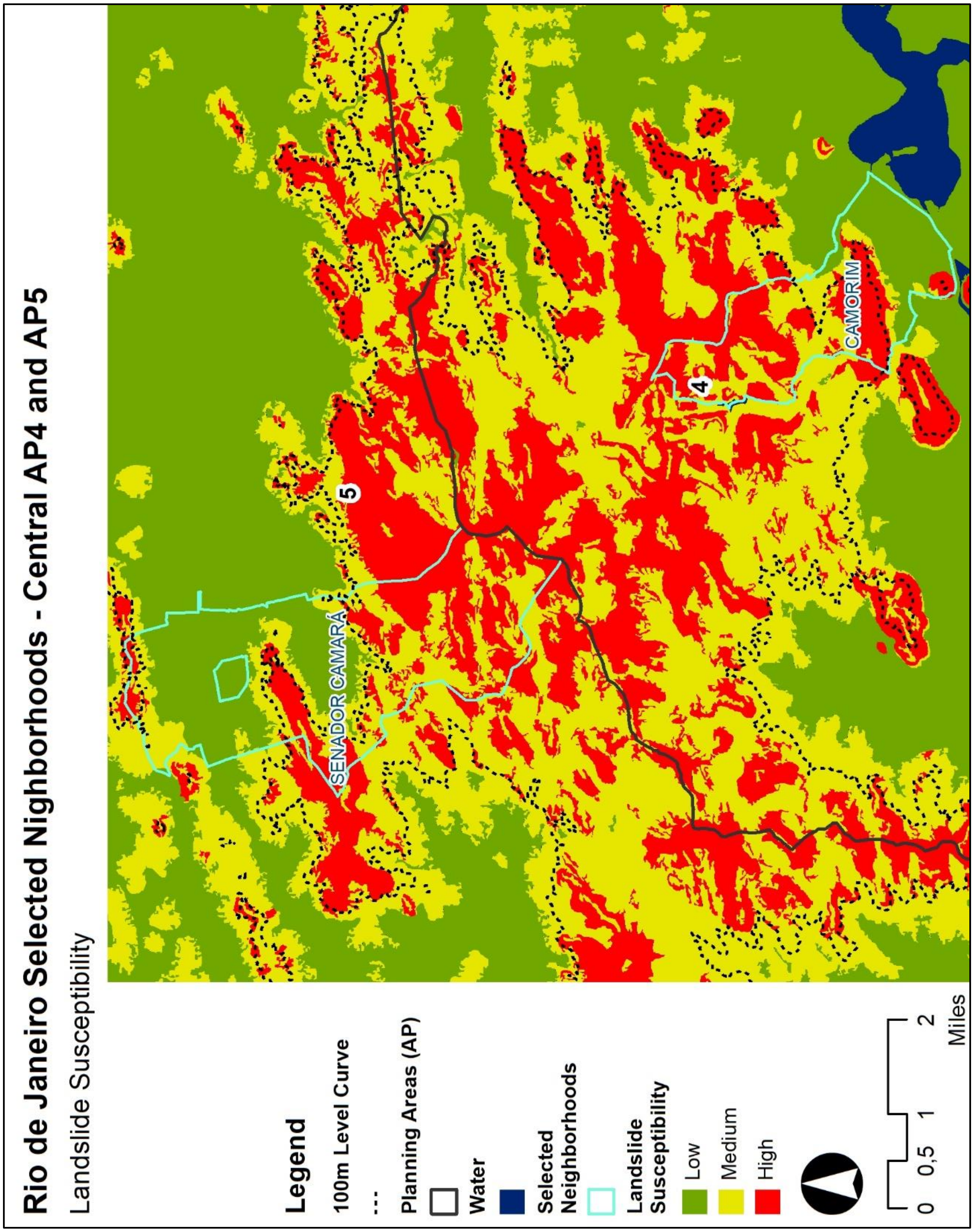
Map 20: Selected Neighborhoods - AP3 Household SVI



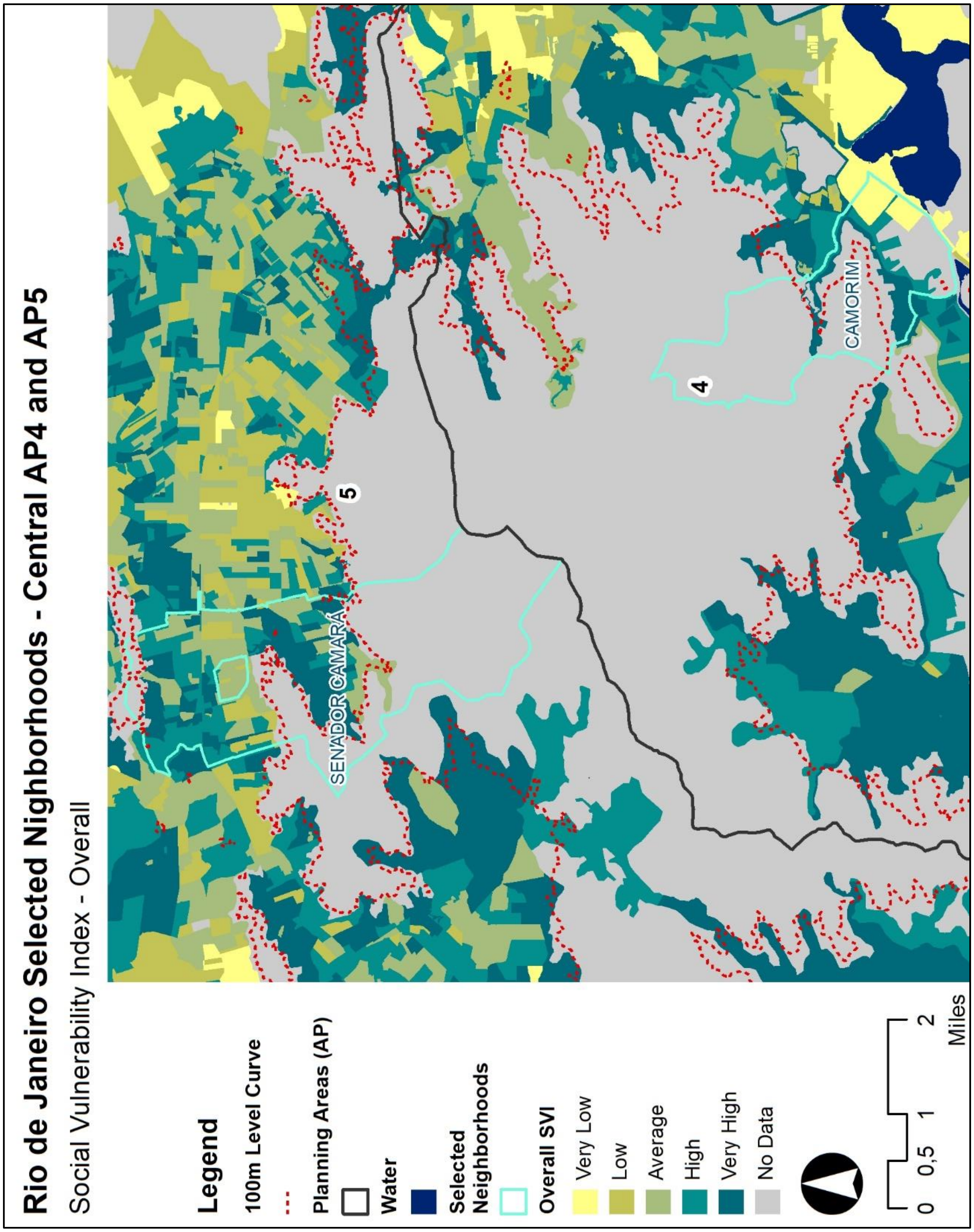
Map 21: Selected Neighborhoods - AP3 Race and Language Vulnerability



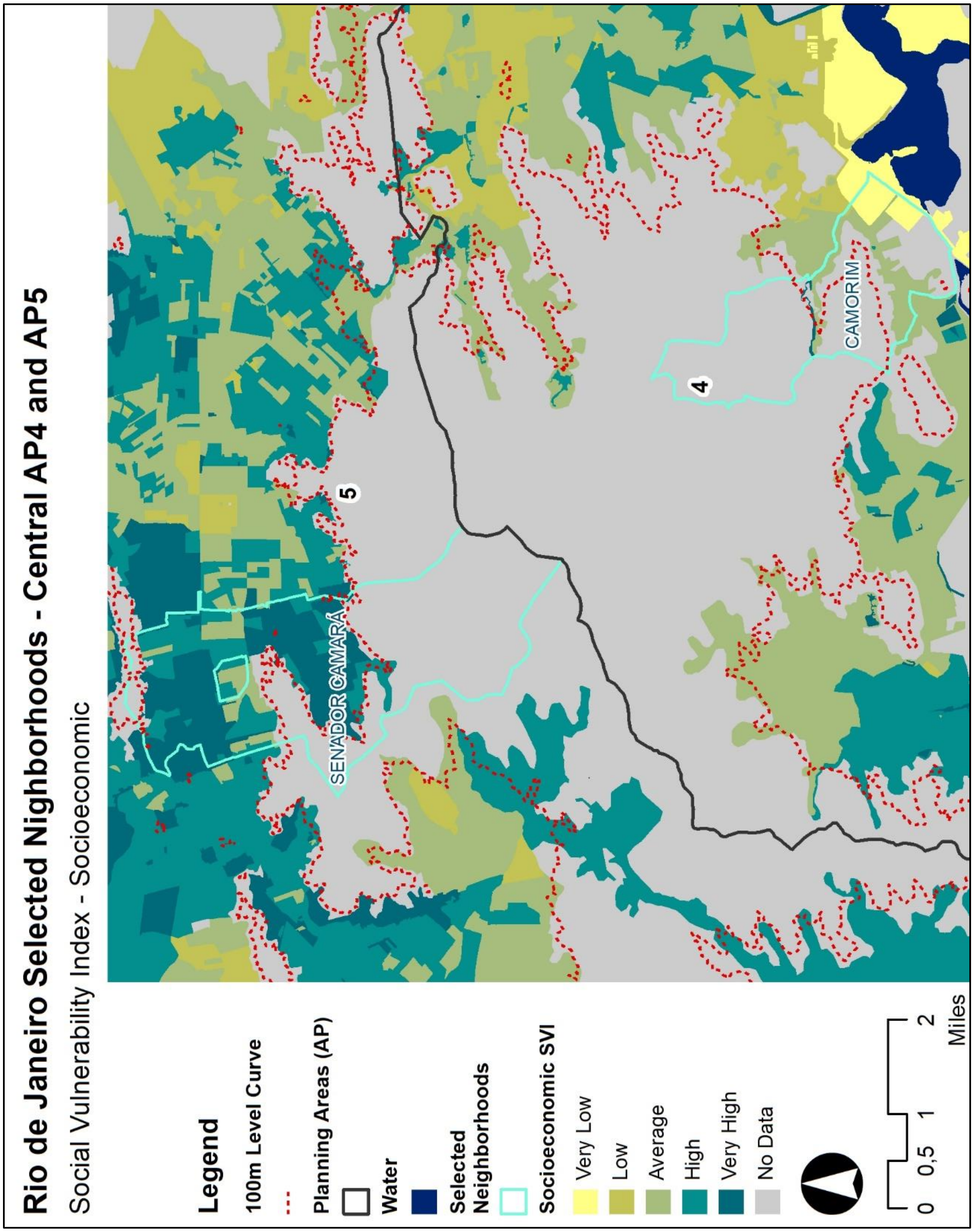
Map 22: Selected Neighborhoods - AP3 Built Environment SVI



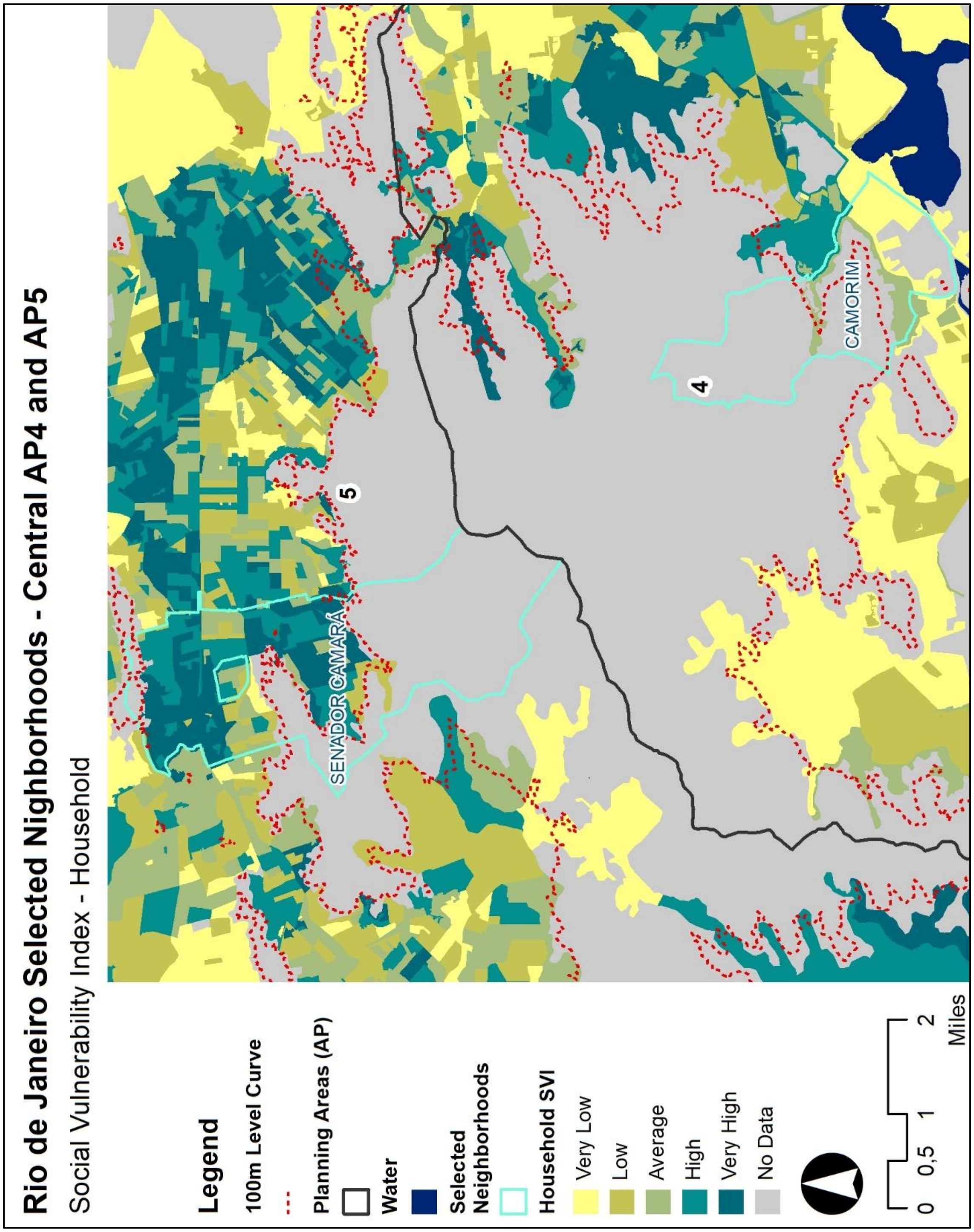
Map 23: Selected Neighborhoods - Central AP4 and AP5 Landslide Risk



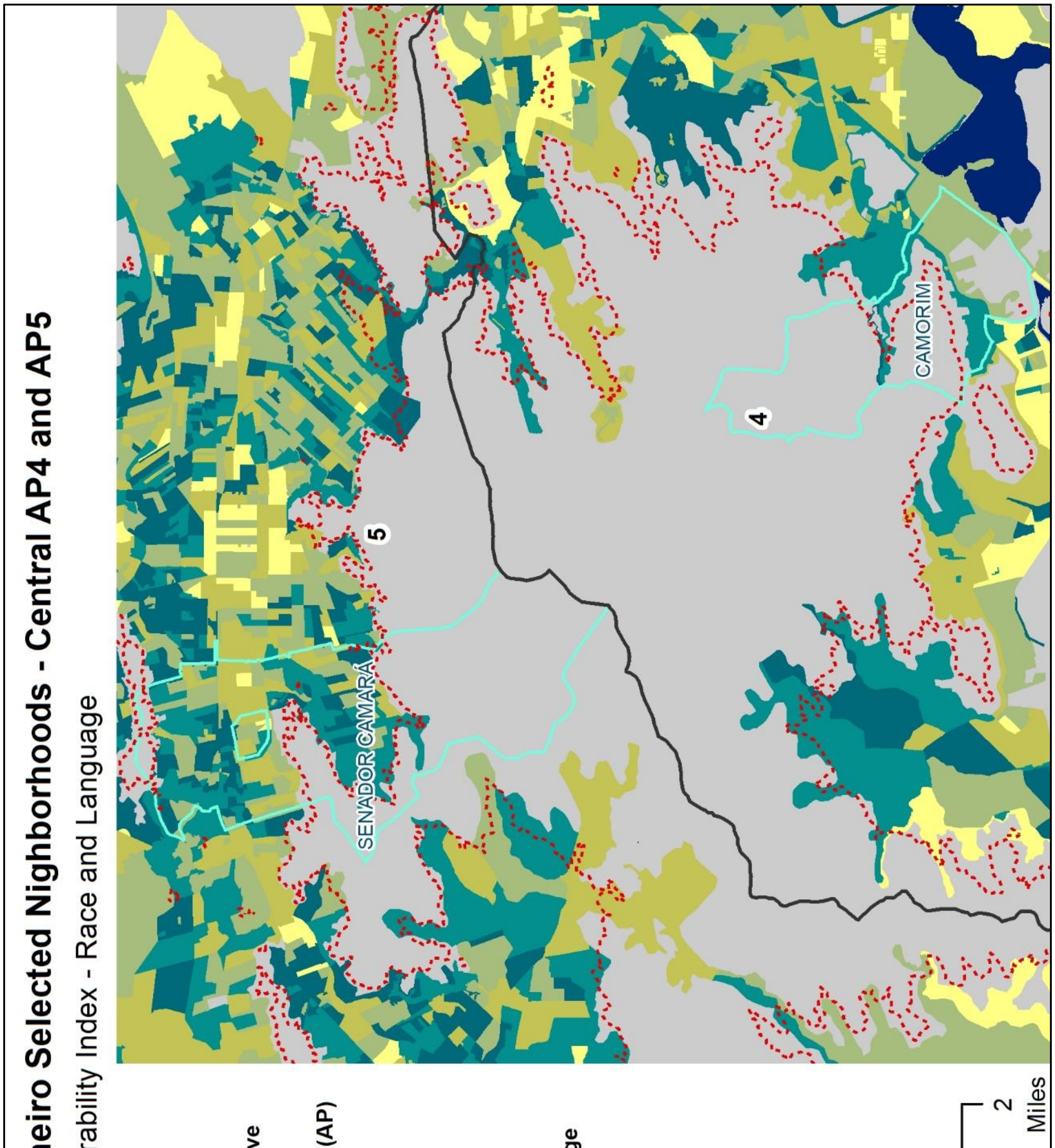
Map 24: Selected Neighborhoods - Central AP4 and AP5 Overall SVI



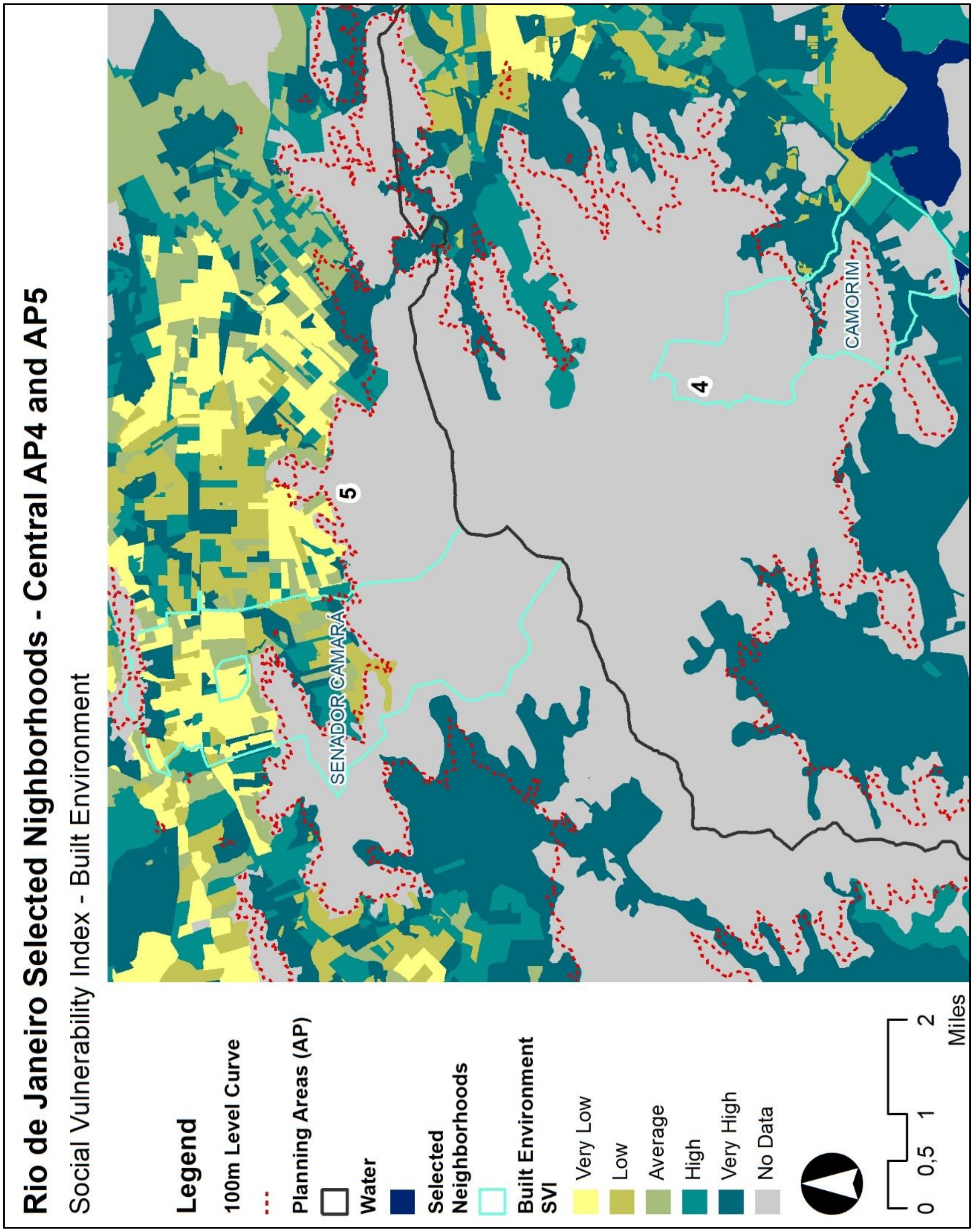
Map 25: Selected Neighborhoods - Central AP4 and AP5 Socioeconomic SVI



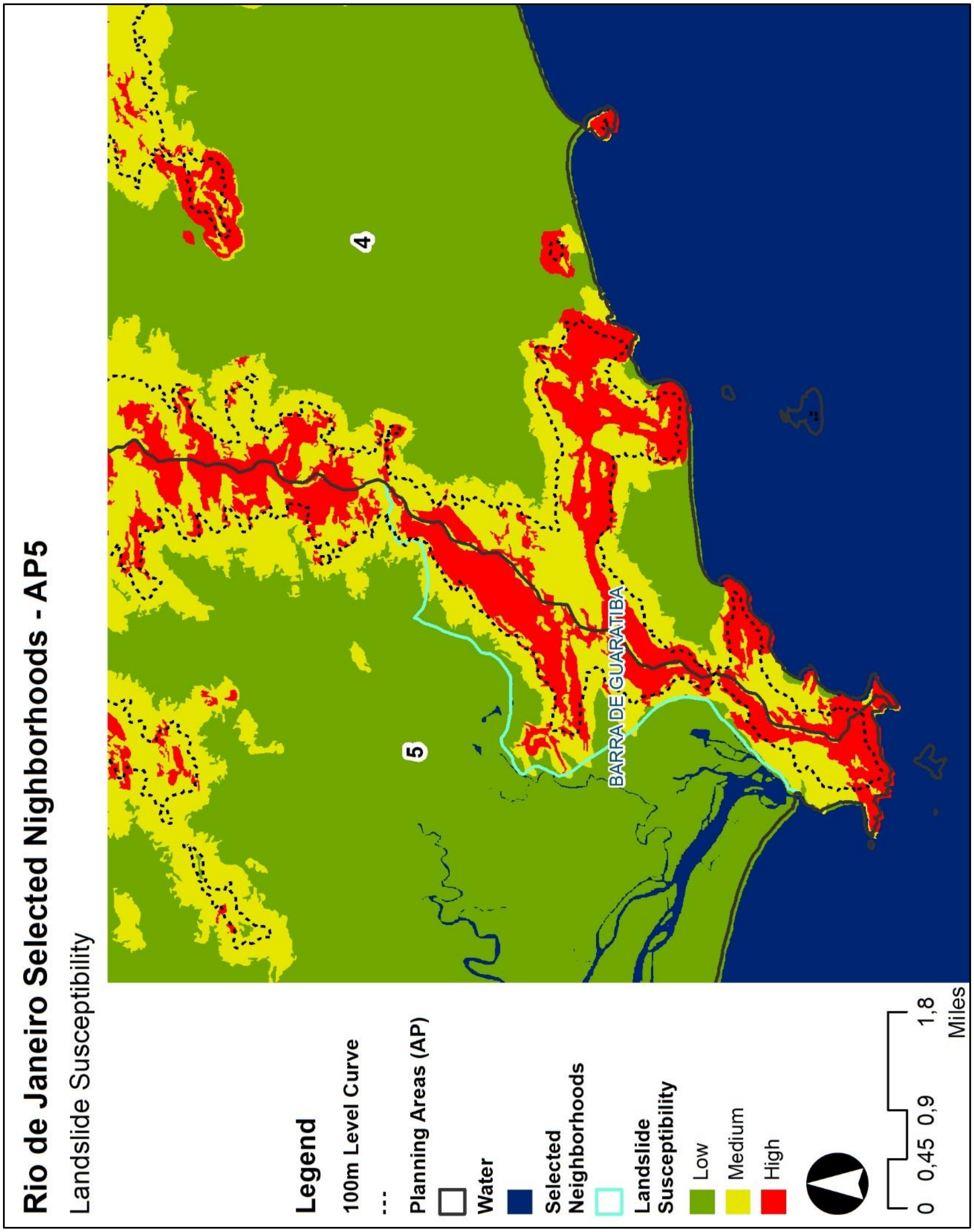
Map 26: Selected Neighborhoods - Central AP4 and AP5 Household SVI



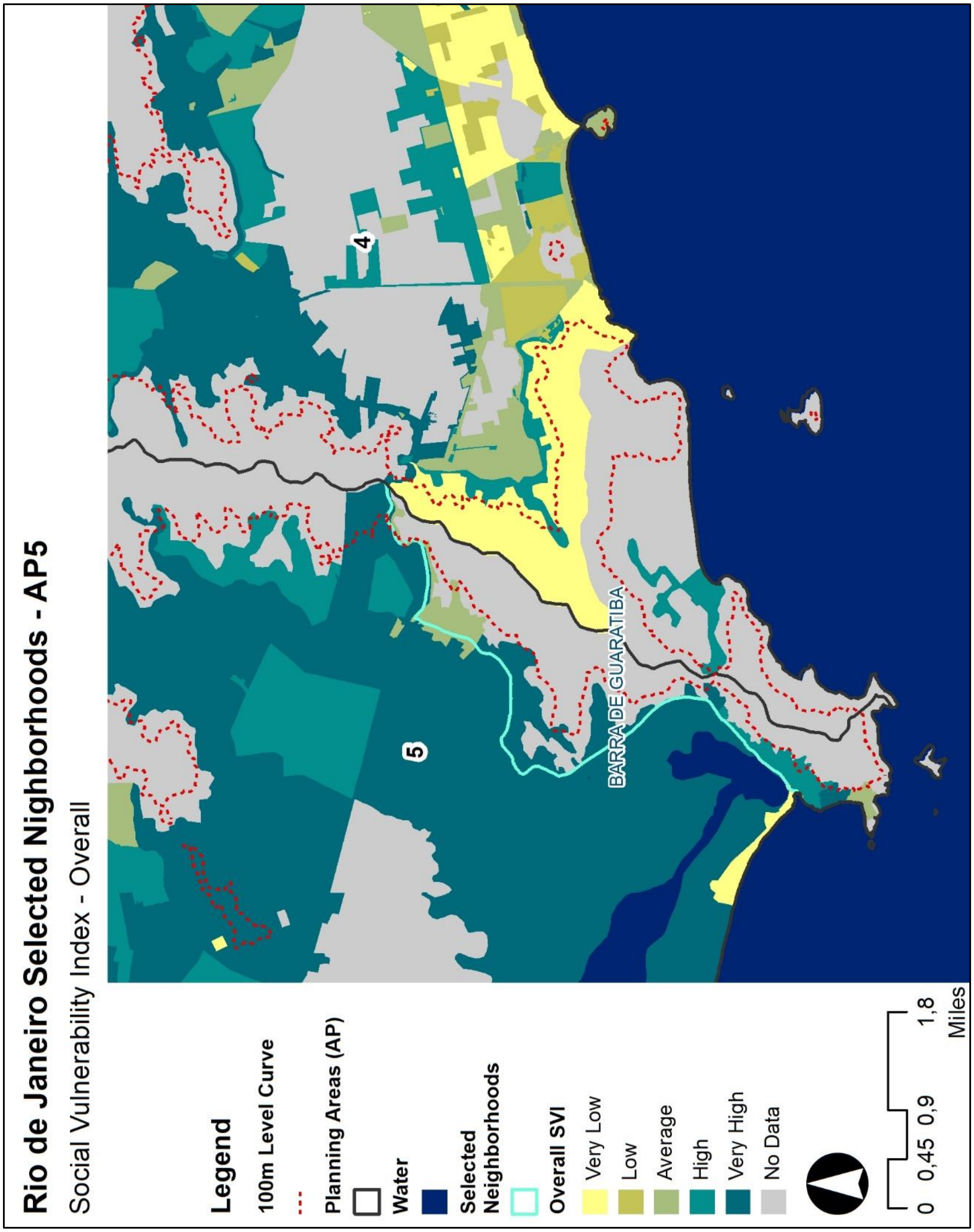
Map 27: Selected Neighborhoods - Central AP4 and AP5 Race and Language SVI



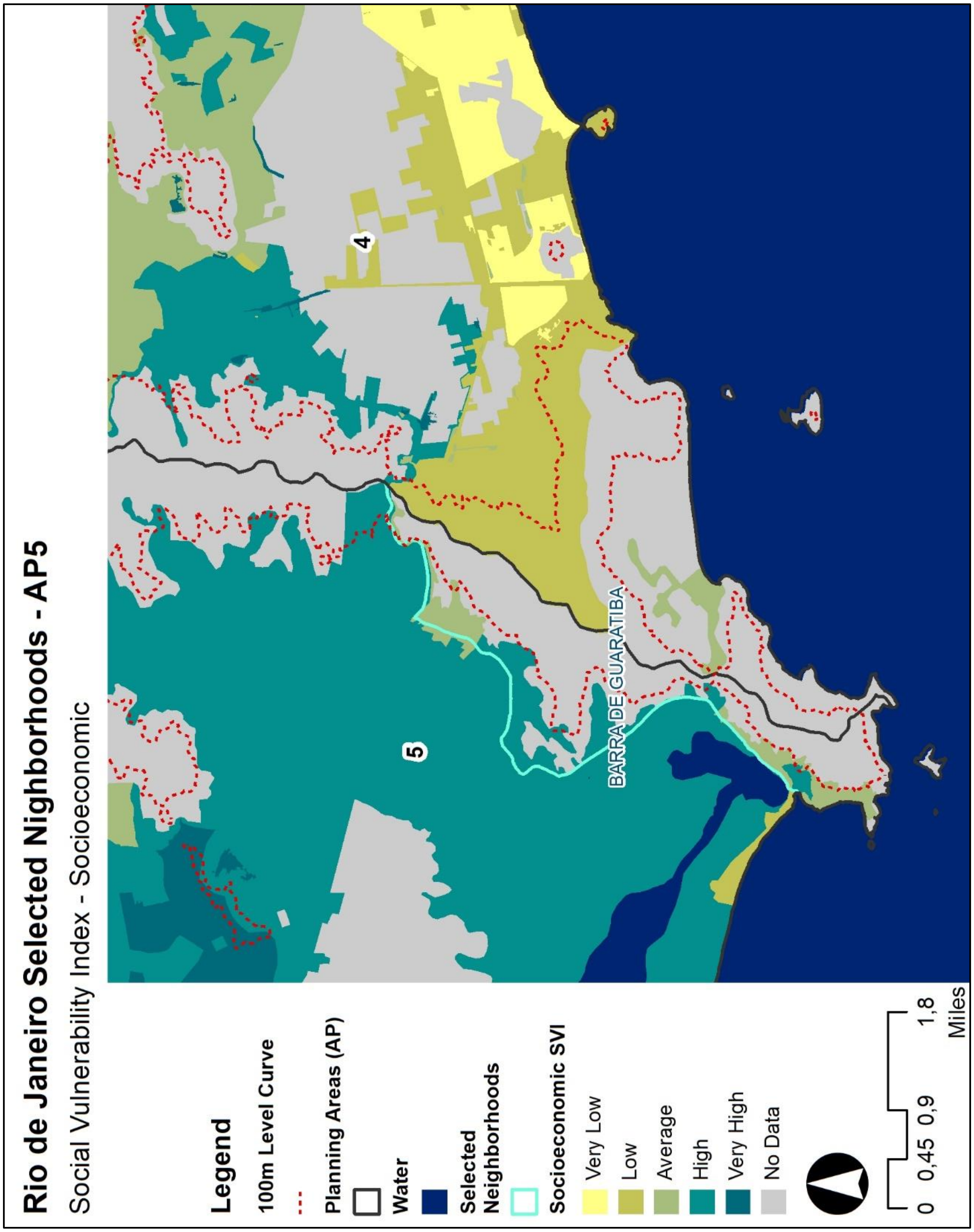
Map 28: Selected Neighborhoods - Central AP4 and AP5 Built Environment SVI



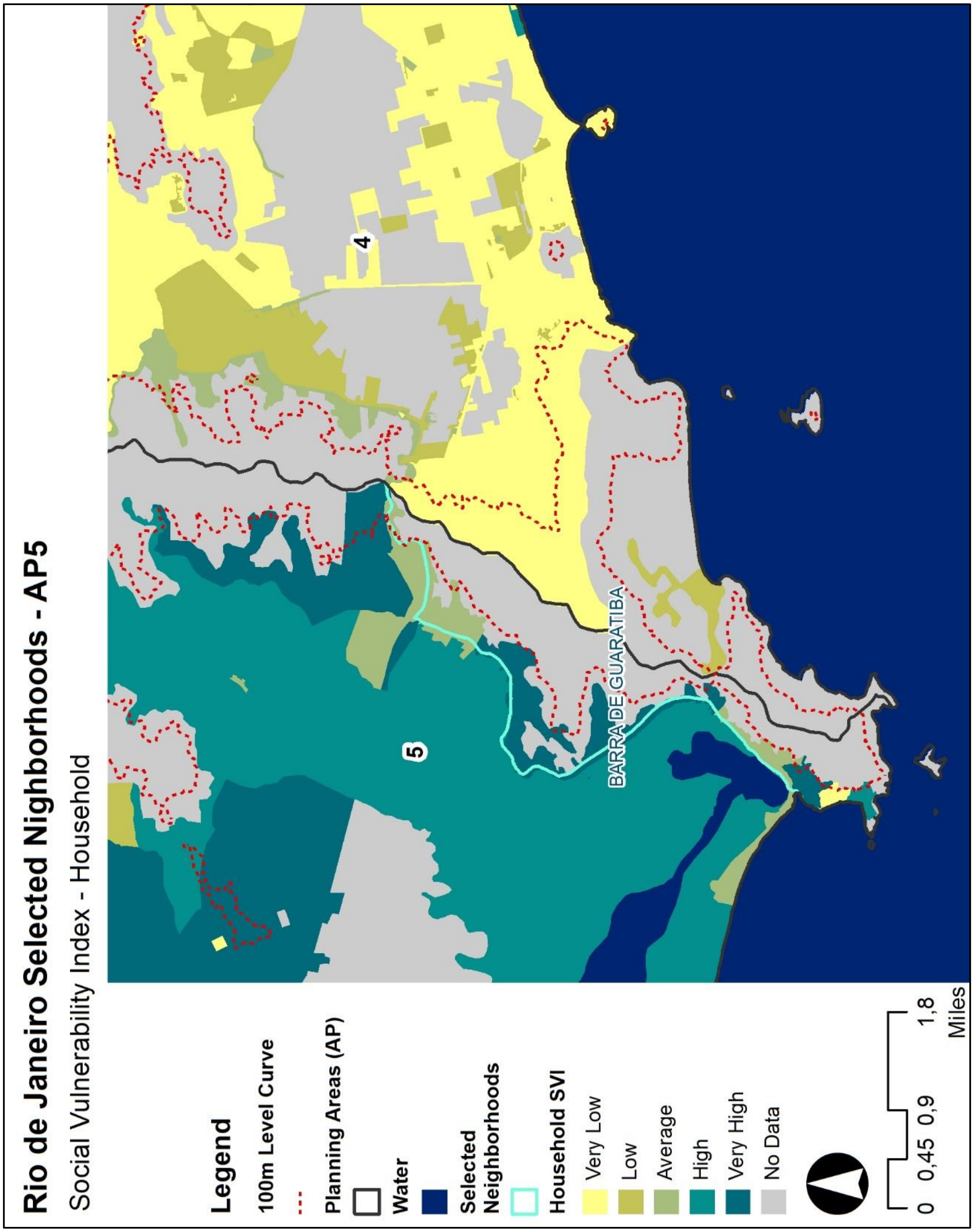
Map 29: Selected Neighborhoods - AP5 Landslide Risk



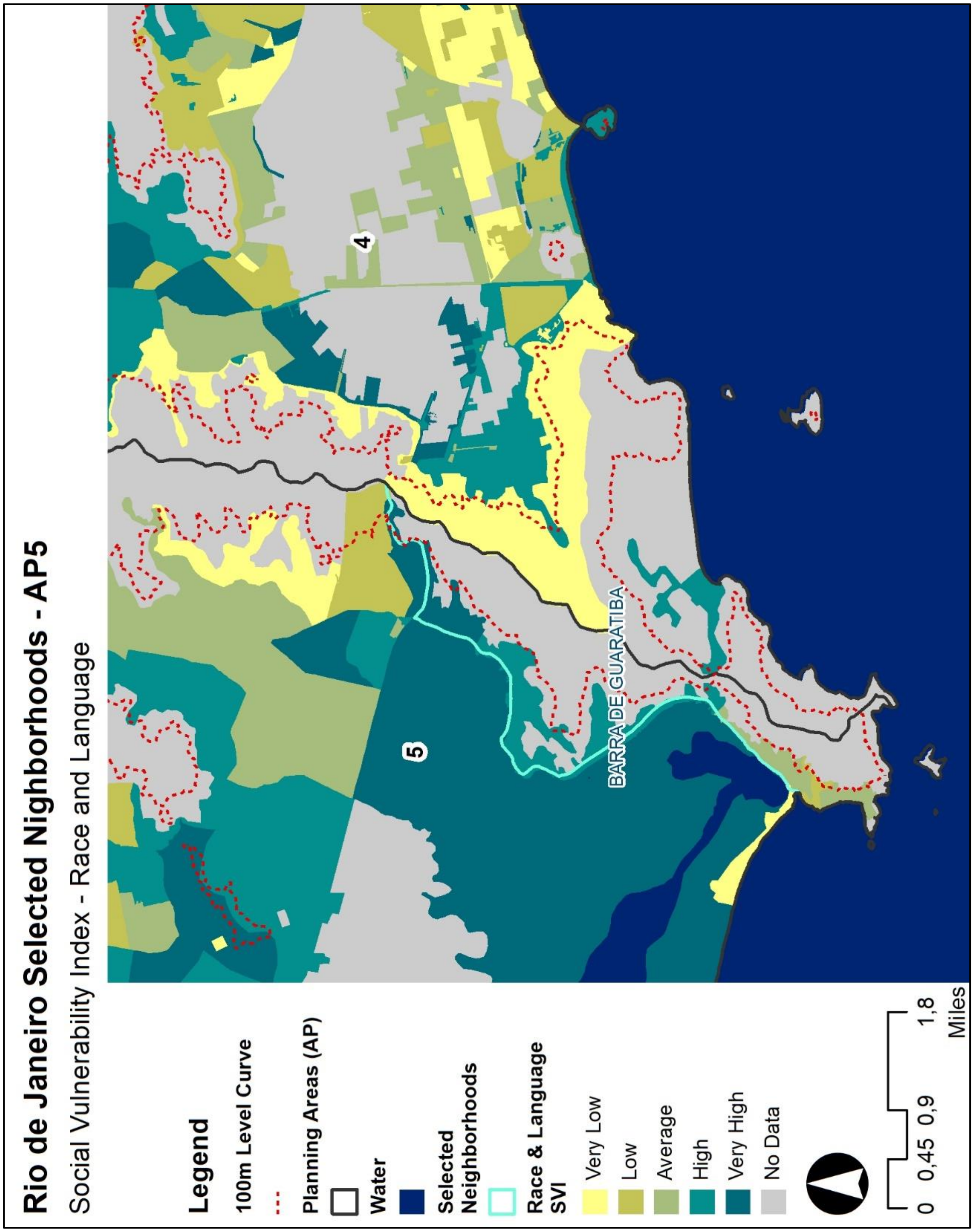
Map 30: Selected Neighborhoods - AP5 Overall SVI



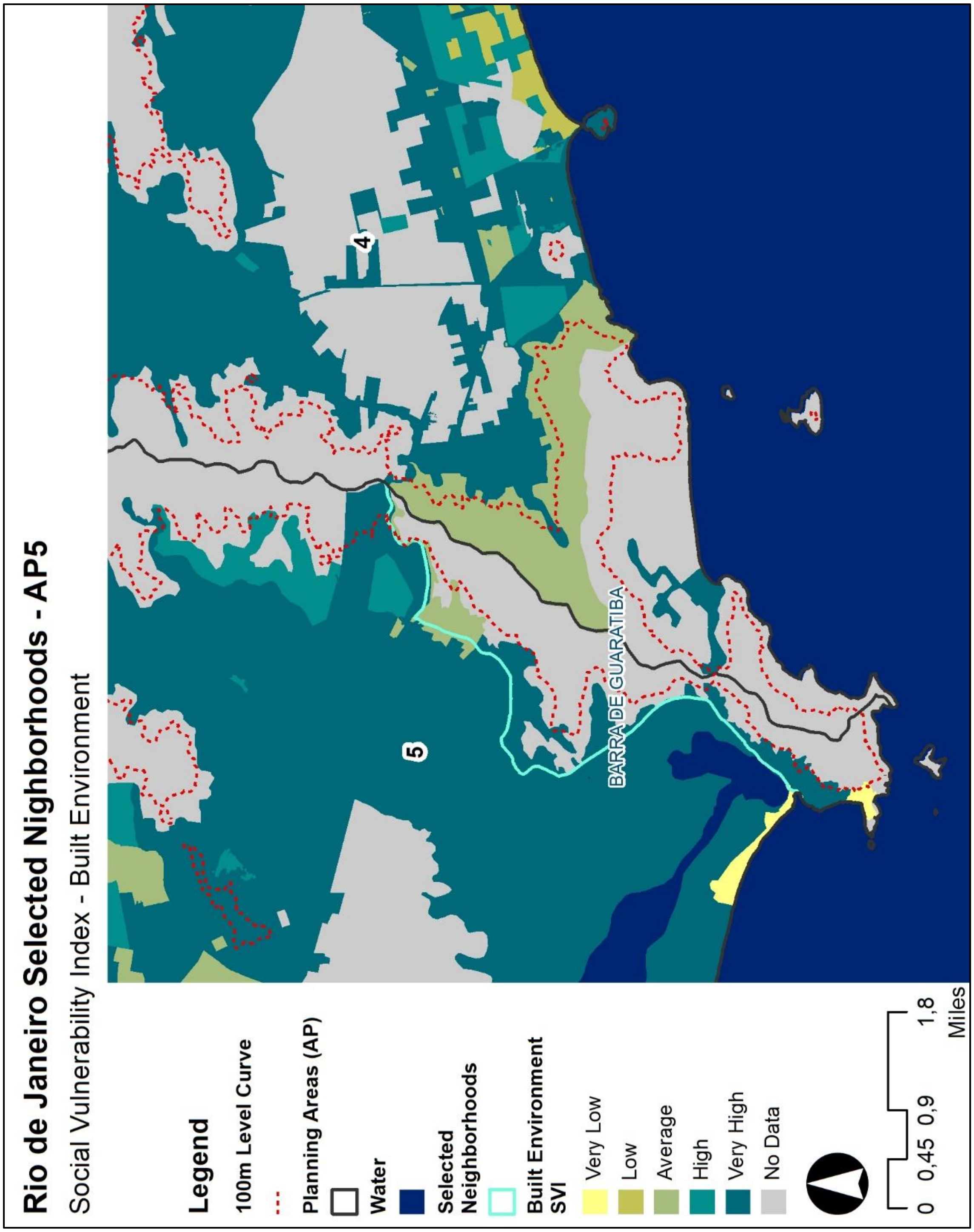
Map 31: Selected Neighborhoods - AP5 Socioeconomic SVI



Map 32: Selected Neighborhoods - AP5 Household SVI



Map 33: Selected Neighborhoods - AP5 Race and Language SVI



Map 34: Selected Neighborhoods - AP5 Built Environment SVI

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